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REMOTE CONTROL BOARD INSTALLED AT THE PINKSTON POWER HOUSE OF THE GLASGOW CORPORATION TRAMWAYS.
This board controls the 6,600-volt, 350,000 kVA metal-clad switchgear illustrated on page 132.

G.E.C. Journal

VOL. III. AUGUST, 1932. No 3.

Gasfilled Relays.

PART II.—PRACTICAL APPLICATIONS.

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The theory of the gasfilled relay and its operation were described in detail in Part I. *of this article, which appeared in the issue of the G.E.C. Journal dated May,* 1932, *Vol.* III., *No.* 2; *it will be useful, however, to summarise the more important principles of its operation before considering uses to which the gasfilled relay may be applied.*

THE gasfilled relay consists of a three-electrode discharge device, in which current may pass between an electron-emitting cathode and an anode under the electrostatic control of a third electrode, or grid, which shields the cathode from the anode. The presence of a gas or metallic vapour in the discharge space gives to the tube the characteristic properties upon which its practical usefulness is based.

The gasfilled relay, considered as part of an electric circuit, is characterised in having two distinct possible states. In the first, it is a non-conductor, that is no current will pass between the cathode and anode when a potential difference is applied. The necessary condition that the tube should remain in this state is that the grid voltage should be sufficiently negative with respect to the cathode to provide an electrostatic field of sufficient strength to prevent any electrons from escaping from the immediate neighbourhood of the cathode. The least value of negative grid voltage in order to accomplish this is $1/\mu$ times the positive voltage applied to the anode, where μ is a constant depending upon the construction of the tube. In the second or conducting state, the gaseous content of the tube is ionised by collision, initially by electrons escaping from the cathode, and a current passes between cathode and anode. This current is carried mainly by electrons but also by positive gaseous ions, which are continually renewed by the passage of the current. The presence of positive ions in the discharge path results in the neutralisation of the negative space charge due to free electrons, and the consequent impedance to the free passage of electrons through the discharge space is reduced to zero.

The total loss in the tube (excluding the energy used in heating the cathode) is equivalent to a back e.m.f. of 12 to 15 volts (for mercury vapour). The current that will pass through the tube is therefore limited by the impedance of the external circuit alone. A further effect of the presence of positive ions is to stop the controlling action of the grid electrode, since a negative voltage on the grid causes it to attract to itself a sheath of slow-moving positive ions which form an electrostatic screen between the grid and the discharge space, and render ineffectual any further change in grid potential. Thus, once ionisation has been set up in the tube, the grid has no further control, and consequently the tube must remain in the ionised (and conducting) state indefinitely, unless the anode-cathode circuit is broken externally, or the anode voltage is reduced below that necessary to sustain a discharge. After allowing a sufficient time for the ionisation to disperse (which may vary from 10 to 1,000 micro-seconds according to the design, temperature and operating conditions), upon restoring the anode

voltage the tube will remain in the non-conducting state if, and only if, the grid has a sufficiently negative potential.

The condition that the tube shall pass from the non-conducting to the conducting state is that an electron or electrons shall escape from the neighbourhood of the cathode and, in passing to the anode, acquire sufficient velocity to cause cumulative

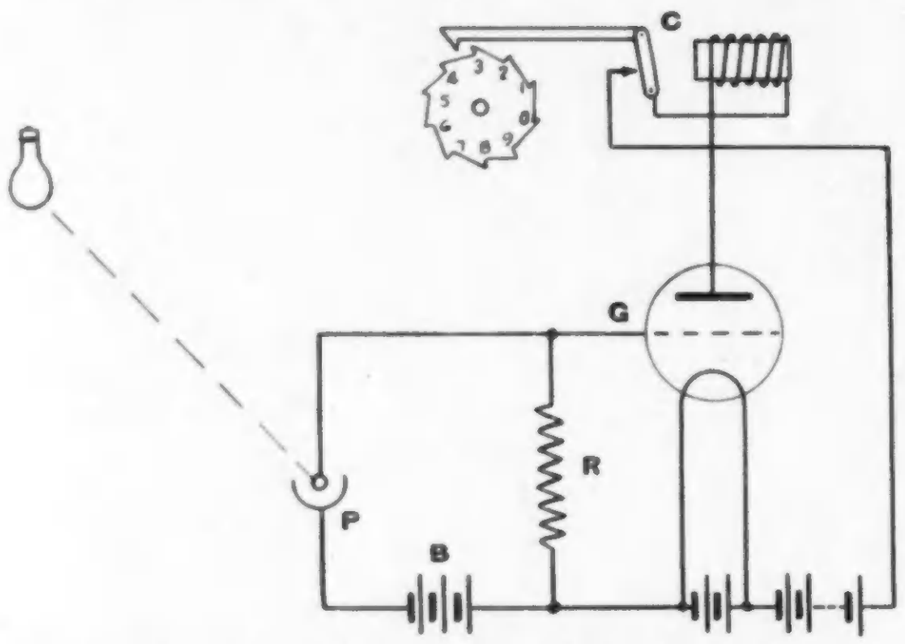


Fig. 13.—Photoelectrically controlled gasfilled relay for counting passing objects.

ionisation by collision. This will occur when the negative grid voltage is reduced below a certain critical value dependent upon the anode voltage. The ratio $\mu = \frac{\text{anode voltage}}{\text{critical grid voltage}}$, called the "grid control ratio," is in many types of gasfilled relay a

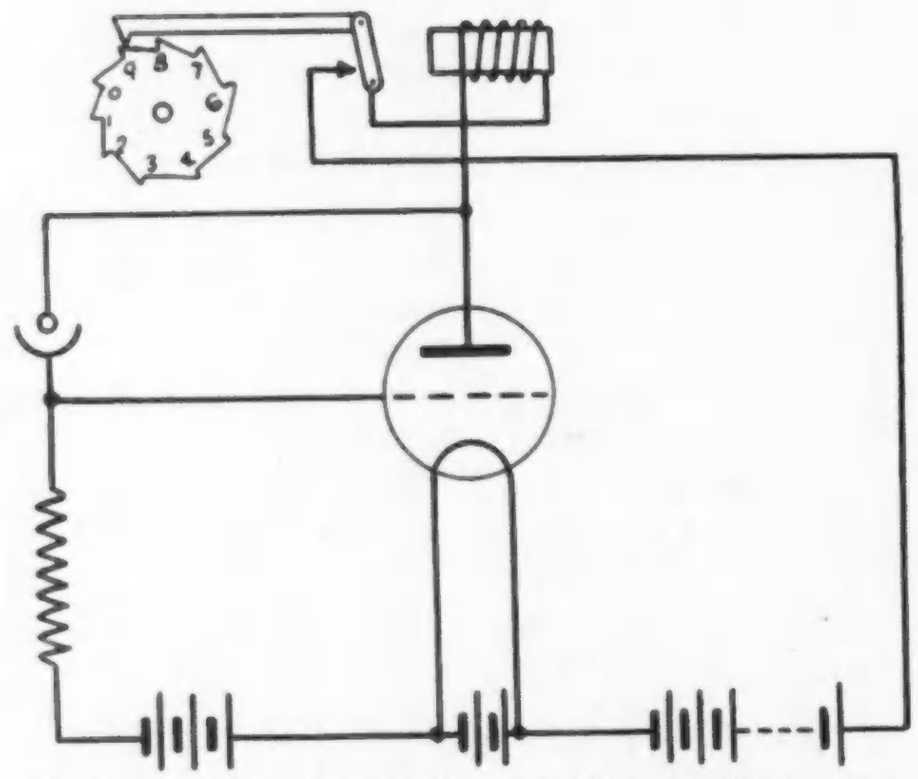


Fig. 14.—Photoelectrically controlled gasfilled relay for counting flashes of light.

constant for a wide range of anode voltage. In tubes, however, designed to have a large value for μ, in which the mesh of the grid is very fine, the proportionality between anode voltage and critical grid voltage is not exact, and in some cases the critical grid voltage has a constant *positive* value irrespective of anode voltage.

The fundamental principles of operation upon which all applications of the gasfilled relay are based are therefore:

(*a*) Upon applying anode voltage the gasfilled relay will not pass anode current provided the grid voltage is sufficiently negative.

(*b*) Upon reducing the negative grid voltage (or increasing the anode voltage) beyond a certain critical value, current passes between anode and cathode, the gaseous content being ionised. In this condition the voltage drop across the tube is constant (about 15 volts for mercury vapour) irrespective of the value of anode current flowing, and the latter is limited only by the external circuit conditions. The grid has no further control either to extinguish or to reduce the current.

(*c*) The discharge can only be stopped by breaking the anode circuit or by reducing the anode voltage below that required to maintain the discharge.

THE GASFILLED RELAY AS A TRIGGER DEVICE.

The simplest application of the gasfilled relay is in the case where a small variation of grid potential is used to cause the starting of a steady anode current, which will then continue to flow independent of any further variations of the grid voltage. With a steady anode voltage, the grid is biassed sufficiently negatively to withhold the starting of anode current when the anode circuit is closed. Any change of grid voltage, due to change of biassing conditions, or to a superimposed voltage, whereby the grid potential is momentarily made more positive than the critical value, results in the starting of the anode current and the appearance of the characteristic glow of the discharge throughout the tube. Thus a gasfilled relay will provide a permanent indication of a single transient effect of any kind which can be converted into a voltage variation, such as slight overload of voltage or current, however short in duration, a temporary breakdown or a mechanical shock. The anode current may be made to perform various appropriate functions, such as working an alarm, starting up a D.C. motor or operating a relay. Or, for instance, the gasfilled relay may be used in conjunction with a contactor to open a circuit in the event of an overload occurring in that circuit.

When operated in this manner, the gasfilled relay is reset by breaking the anode circuit for an interval of sufficient duration to enable the grid to regain control of the discharge. If the anode current is made to actuate a relay breaking its own circuit, the gasfilled relay is automatically reset each time that it is operated, and by the addition of a suitable counting mechanism, provides a means for counting recurring grid voltage variations. It is, of course, necessary in order to prevent multiple operation of

the counting device, that the duration of each impulse applied to the grid be less than the operating time of the counting relay.

In this connection a photoelectric cell is a suitable and useful means of applying to the grid of the gasfilled relay impulses in accordance with variations of illumination. A circuit of this type is shown in fig. 13. While light is falling on the photoelectric cell P, a current from the battery B passes through it, keeping the grid of the gasfilled relay G at a negative potential. When the light is cut off by a passing object, the photoelectric current is interrupted and the grid assumes cathode potential through the resistance R. Anode current then flows, operating the counting relay, which also breaks the anode circuit, permitting the grid to regain control of the discharge. The device counts the number of times the light beam is interrupted by passing objects. Here again, in order to prevent multiple operation of the counting mechanism, it is necessary that the time taken by the objects in passing through the beam of light be less than the operating time of the counting relay. For slowly moving objects, therefore, this circuit is not suitable, and in such cases it is preferable to use combinations of photoelectric cell and gasfilled relay operated by alternating current, which will be described later in this article. A circuit similar to that of fig. 13 is shown in fig. 14, but in this case the gasfilled relay is operated each time light falls on the photoelectric cell. This circuit forms a counter for light flashes.

The mechanical inertia of the counting device imposes a limit upon the rapidity with which these circuits will work, but by the successive use of a number of gasfilled relays the possible speed of counting may be multiplied by any desired factor. A circuit capable of counting up to 1,000 events per second, due to Wynn-Williams*, and used by him to count α-particles is given in fig. 15. The voltage impulse due to the arrival of each α-particle upon a collecting surface is applied, after suitable amplification, through condensers to the grid of each of several gasfilled relays arranged in a ring circuit. The voltage of each impulse is alone insufficient to trigger off any tube. If, however, there is already anode current passing through one of the tubes, the grid of the next tube in the ring is given a "priming voltage" obtained from a tapping on the anode resistance of the previous tube. Helped by this "priming voltage," the next impulse to arrive is able to strike the tube, the anode current of which "primes" the succeeding tube. Thus each impulse triggers a further tube, and the operation continues throughout the ring endlessly. The tubes are reset in turn by a relay operated by the anode current of the succeeding tube, one of these relays being made to count the number of times the cycle of operation passes round the ring. As each relay has nearly the whole time of the cycle in which to operate, any rate of impulse arrival can be catered for by the use of a sufficiently large number of gasfilled relays.

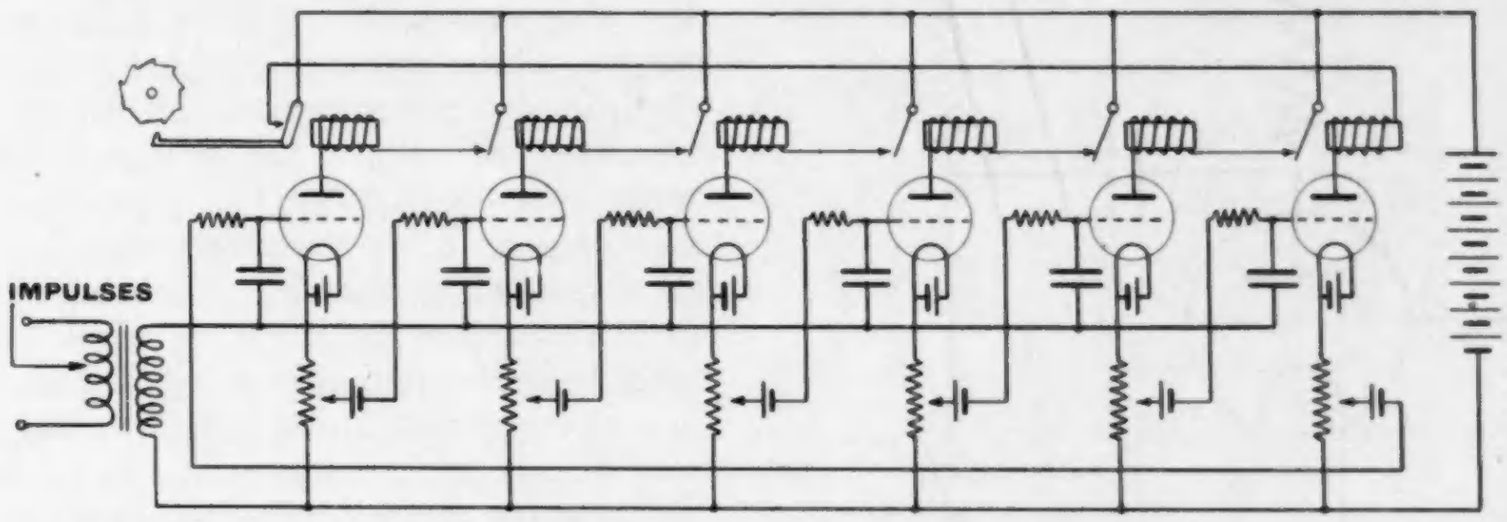


Fig. 15.—Composite counting circuit for measuring the rate of arrival of α-particles.

* { Proc. Roy. Soc. 2 July, 1931. A819. p.295.
Proc. Roy. Soc. 2 May, 1932. A829. p.312.

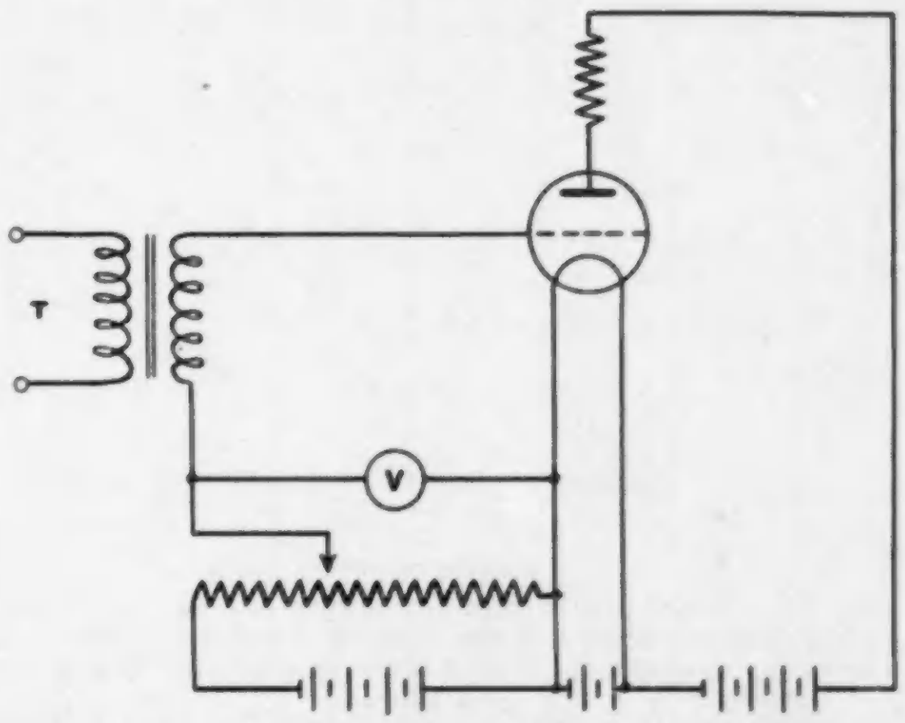


Fig. 16.—Circuit for measuring peak voltages.

MEASUREMENT OF TRANSIENT VOLTAGES.

Besides denoting the arrival upon its grid of a positive voltage impulse, the trigger action of a gasfilled relay may be utilised to determine whether the voltage of such an impulse exceeds any predetermined amount, and hence, when the impulses

can be repeated, of measuring their peak voltage. In the circuit shown in fig. 16, with constant anode voltage, the impulses to be measured are applied to the grid through the transformer *T*, and superimposed upon them is a variable D.C. bias. This bias is increased negatively until the gasfilled relay

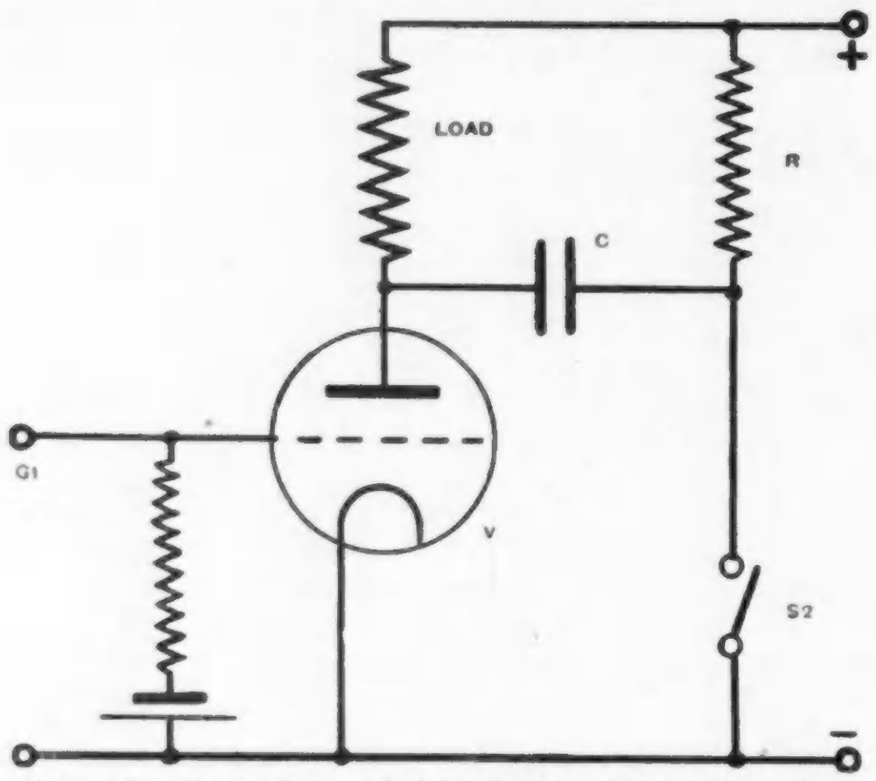


Fig. 17.—Extinction of the anode current of a gasfilled relay by the sudden discharge of a condenser.

can just no longer be triggered by the impulses. Then the difference between the applied grid bias measured by the voltmeter *V*, and the critical bias (the bias when tube is just triggered, the impulses being absent), gives the peak value of the voltage of the impulses. In a similar manner gasfilled

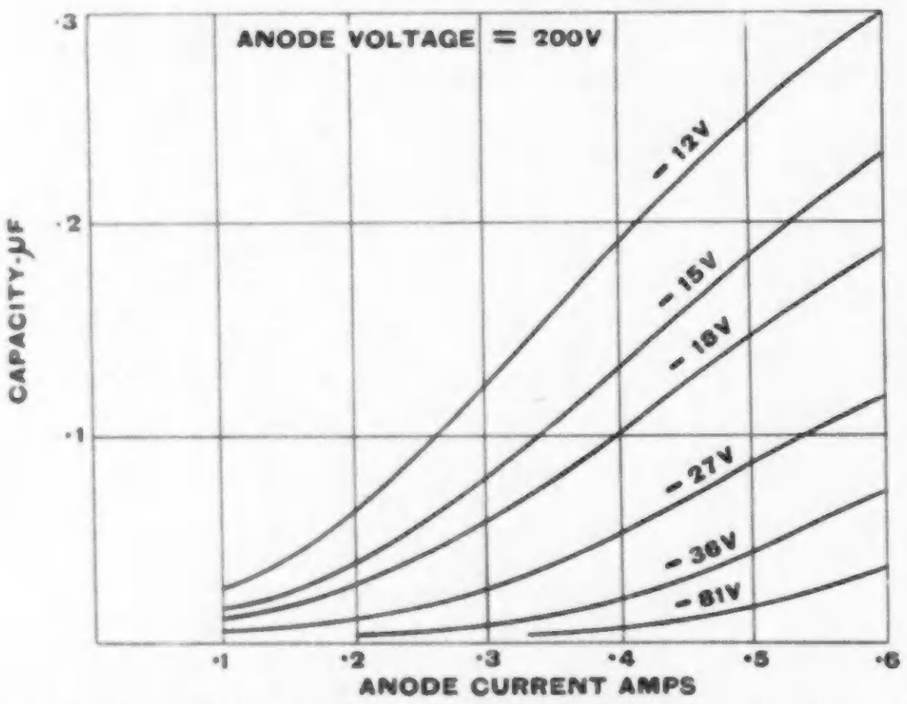


Fig. 18.—Relationship between anode current in Osram G.T.1 gasfilled relay and the minimum value of condenser necessary to cause extinction for various values of applied grid bias.

relays may be used to measure the peak values of current surges, and also the values of currents which may only be maintained for very short periods. Thus it is possible to measure the emission from a thermionic filament at a given temperature, where ordinary methods are precluded, because the passage of space current for anything but a fractional time would alter the temperature of the filament and render the measurement valueless.

SWITCHING BY GASFILLED RELAYS.

As already described, the presence of positively charged gaseous ions in the gasfilled relay reduces the voltage drop across the tube during the passage of the arc-like discharge to a small constant value irrespective of the value of anode current flowing. For this reason, the gasfilled relay is capable of carrying large currents without excessive internal dissipation, and moreover, its efficiency is high, especially at high anode voltages. The tube is therefore able to perform the operation of a contactor, switching on heavy currents under the control of a small grid voltage change. The power required by the grid in starting the anode current is infinitesimal, since before ionisation is set up, the grid impedance is very large, and during ionisation, the grid current may be reduced to a small value by the use of a high grid input resistance. The power necessary to start an anode current of several amperes may be only one microwatt.

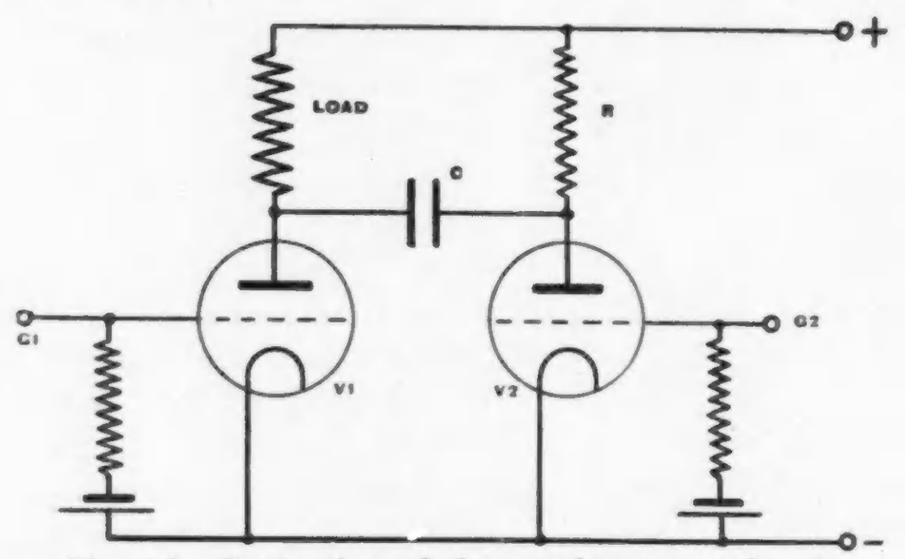


Fig. 19.—Extinction of the anode current by the use of a second gasfilled relay.

INTERRUPTION OF ANODE CURRENT.

Although certain types of gasfilled tubes have been designed in which a high negative grid bias can stop the discharge, this method of interrupting the anode current is not a practical one, as its use is definitely restricted to cases where the anode current is small, and moreover requires considerable power to be applied to the grid in order to remove the positive ion sheath. Usually, therefore, it is necessary to break the anode circuit, or to reduce the anode voltage to nearly zero, in order to interrupt the discharge. One method of reducing the anode voltage is to induce an opposing e.m.f. in the anode circuit by a transformer or other means. The counter-voltage must be at least equal in value to the applied anode voltage and must be of sufficient duration to permit the ions present in the discharge space to disperse. A second method, shown in fig. 17, is by the discharge of a condenser across the tube. When anode current is flowing through the gasfilled relay the condenser *C* becomes charged

through the high resistance R to the potential difference across the load, that is, to a voltage equal to the supply voltage less 15 volts for the drop in the tube. Upon closing the switch S_2, the condenser is applied directly across the anode and cathode, the voltage of the condenser opposing that of the supply. The anode current is therefore interrupted, and a reverse current may flow during that period of the condenser discharge in which there is any ionisation remaining. Hence, when the condenser is large enough to permit a sufficient degree of deionisation during the period of its discharge, the grid will regain control and, if at a sufficiently negative potential, will prevent the restoration of anode current.

The minimum capacity of condenser necessary in order that the anode current shall be stopped is a function of the many factors affecting the deionisation time. In fig. 18 is shown the minimum capacity required to interrupt the anode current for various values of current and of applied grid potential. These curves refer to the Osram G.T.1 gasfilled relay, and were taken with anode currents of short duration. If current has been flowing through the tube continuously for some time a larger condenser is necessary, especially at high currents where a capacity ten times as great as that shown in fig. 18 may be required. This effect is probably due to the heating of the electrodes by the anode current. Variations due to the gas pressure determined by the temperature of the coolest part of the bulb were found to be much less marked, the capacity required being slightly greater both when the temperature was higher and lower than normal.

The function of the switch S_2 in fig. 17 may be performed by a second gasfilled relay. This is shown in fig. 19. When the second tube V_2 is struck by variation of its control grid voltage, the condenser C is discharged through it extinguishing the tube V_1. Similarly when tube V_1 is struck again, V_2 is extinguished. Thus the load current of V_1 may be switched on and off by the control of the voltages of the two grids. The two gasfilled relays therefore form a sensitive and efficient on – off relay, eminently suitable for remote controlled switching.

CIRCUITS FOR CONVERTING D.C. TO A.C.—THE INVERTER.

By suitable modification of the circuit of fig. 19, an efficient method of converting direct into alternating current is obtained. In this circuit, if small alternating voltages are applied to the grids of the two gasfilled relays in opposite phases, current from the D.C. source is diverted alternately through the resistance R and the load resistance at the same frequency as the grid voltages applied. By replacing these two resistances by two primary windings of a transformer, alternating current is induced in the secondary. An inverter circuit of this type in which a small independent A.C. source is used to energise the grids and to control the frequency of the output is shown in fig. 20. In fig. 21, part of the output of the inverter itself is fed back to energise the

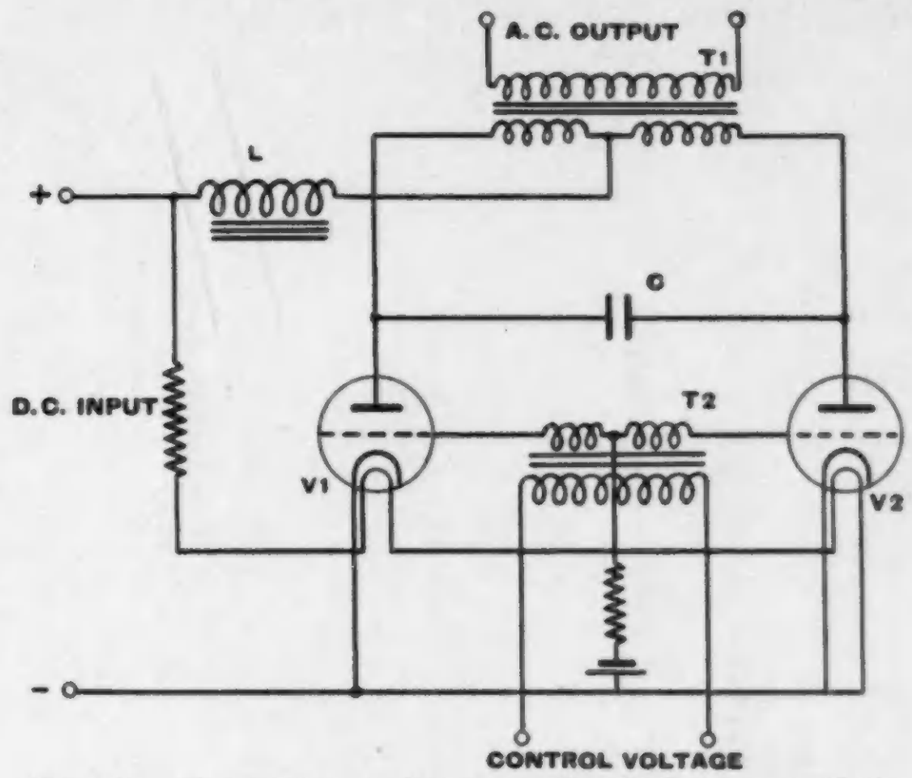


Fig. 20.—Parallel type inverter circuit for converting D.C. to A.C.

grids, and in this case the inverter is self-excited. The frequency of operation is determined by the time constants of the circuit and may be controlled by the adjustment of the values of the condenser C_3 and resistance R. The condenser C_2 ensures that the phase of the grid voltage waves is in correct relationship with that of the anodes.

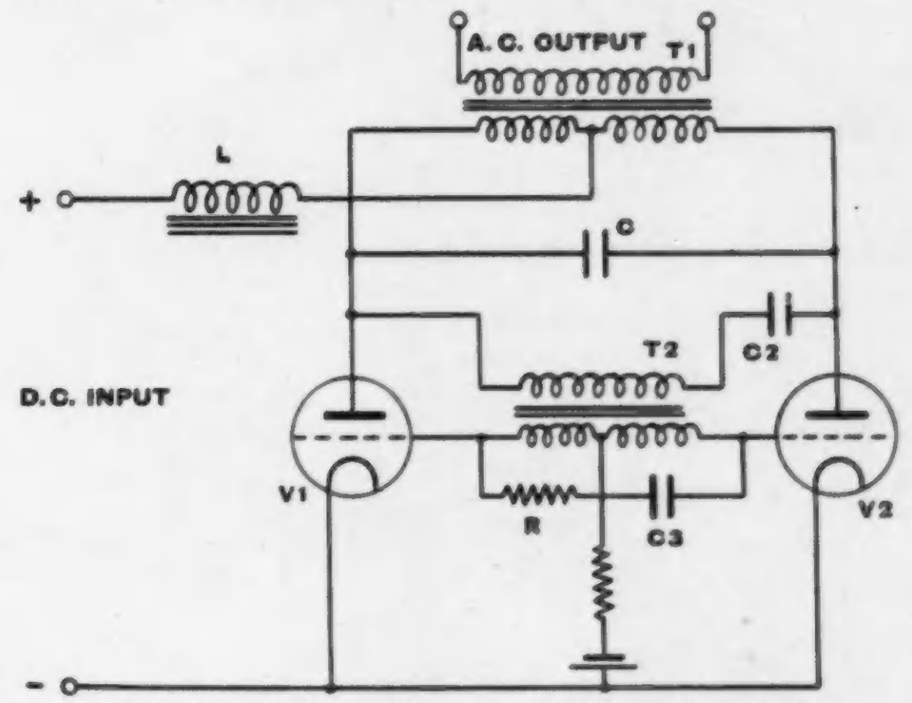


Fig. 21.—Self-excited parallel type inverter.

The employment of gasfilled relays gives to inverter circuits a remarkably high overall efficiency. The chief source of loss is in the voltage drop across the valves, which, being of the order of 15 to 20 volts, means that efficiencies of 99 per cent and over are feasible at high voltages of the D.C. supply. At these high voltages inverters promise to be of great value, since the construction of rotating machinery for operation from high voltage D.C. is

of prohibitive cost due to the difficulty of insulating the moving parts.

When it is required to supply polyphase alternating current, the simple inverter circuit is readily adapted for the purpose. Two types of three phase inverter are illustrated in figs. 22 and 23.

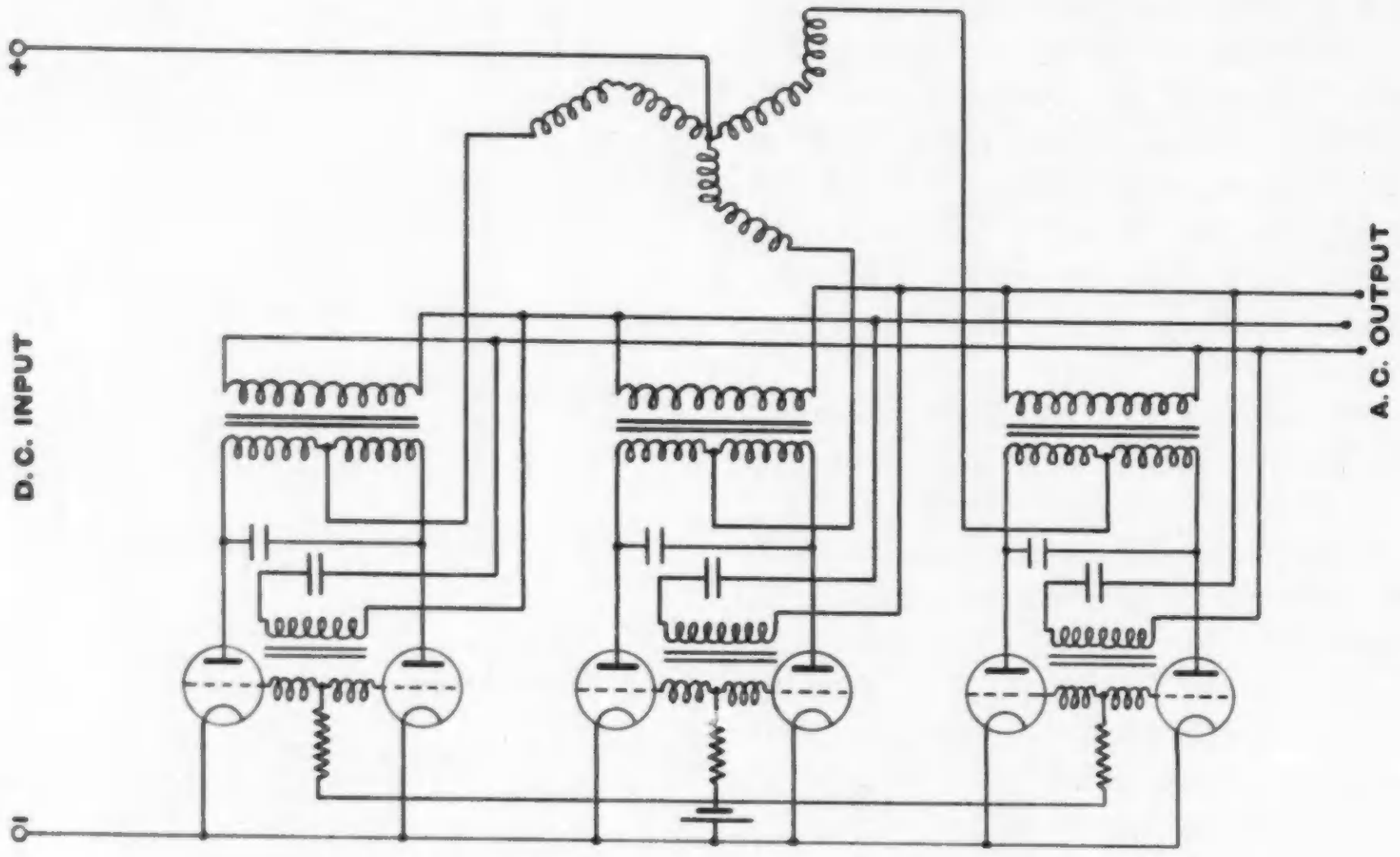


Fig. 22.—Three phase parallel type inverter.

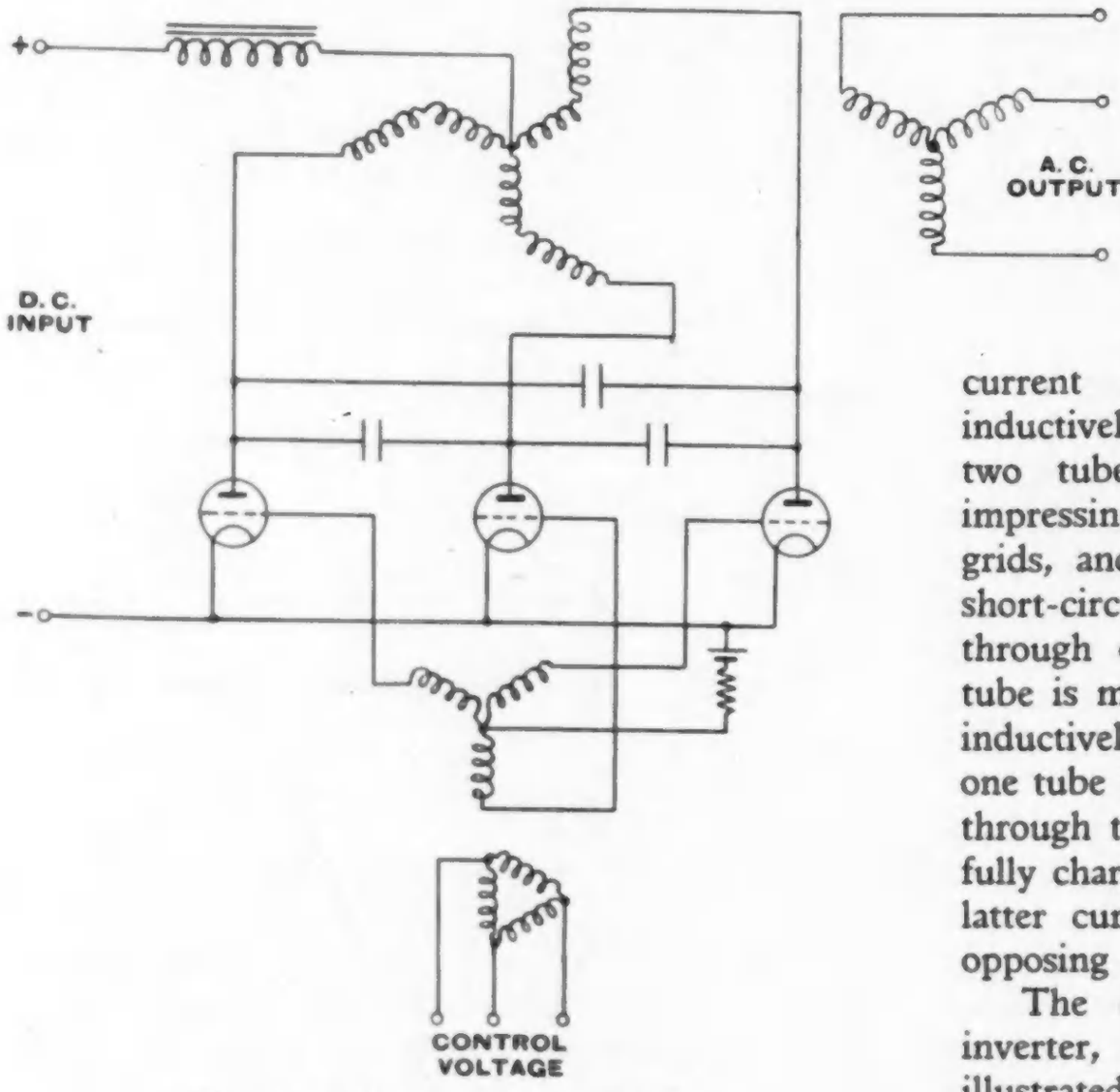


Fig. 23.—Three-phase inverter.

A combination of an inverter and a full wave rectifier using gasfilled valves, which together constitute a D.C. transformer, is shown in fig. 24. The use of a main transformer common to both inverter and rectifier, together with a second "harmonic" transformer, coupling the two direct current leads, results in a very high efficiency of conversion. The square wave form of the inverter output enables a smooth D.C. output to be obtained more easily.

THE SERIES INVERTER.

A second type of inverter employing gasfilled relays, due to Sabbah,* is shown in fig. 25. The principle of operation lies in the charging of a condenser C through one gasfilled relay V_1 and the discharging of it through a second tube V_2, the alternating current circuit through the condenser being inductively coupled to the A.C. load circuit. The two tubes are made conducting alternately by impressing a suitable alternating voltage upon their grids, and as it is necessary (in order to prevent short-circuiting the D.C. supply) that the current through one tube shall be zero when the other tube is made conducting, the two tube circuits are inductively coupled by the choke L. If then, when one tube is struck there is still any current passing through the other (due to the condenser not being fully charged or discharged as the case may be) the latter current is immediately extinguished by the opposing e.m.f. induced in the choke.

The circuits of a self-excited "series type" inverter, and of a polyphase series inverter are illustrated in figs. 26 and 27 respectively.

CAPACITY OF INVERTERS.

The amount of power which a single inverter can handle depends on the current carrying capacity

* Gen. Elec. Rev. May 1931.

of the gasfilled relays used and on the voltage of the D.C. supply. These two factors are determined respectively by the emission of the cathode (for thermionic cathodes), and upon the voltage which the tubes can withstand between anode and cathode when in the non-conducting state. Tubes of the hot-cathode mercury-vapour type have been constructed with emissions of 100 amperes and a working voltage of 15,000. An inverter using two such tubes could handle 1,500 kilowatts at an efficiency of about 99.5 per cent. For larger outputs mercury pool cathodes may be used. Fig. 28 shows an inverter of such a type. The construction of the apparatus is similar to that of the familiar mercury-vapour rectifiers used in traction work, but with the addition of grids which completely screen electrically each anode from the cathode. Owing to the fact that there is ionisation continually present in the vessel (due to the subsidiary arc used to maintain an electron-emitting spot on the surface of the cathode) a relatively large current is taken by each grid in withholding the discharge from the corresponding anode and a relatively large amount of power is therefore required by the grids of inverters using discharge vessels of this type. Usually the grids are excited from a special generator or battery through a commutator rotated synchronously with the output.

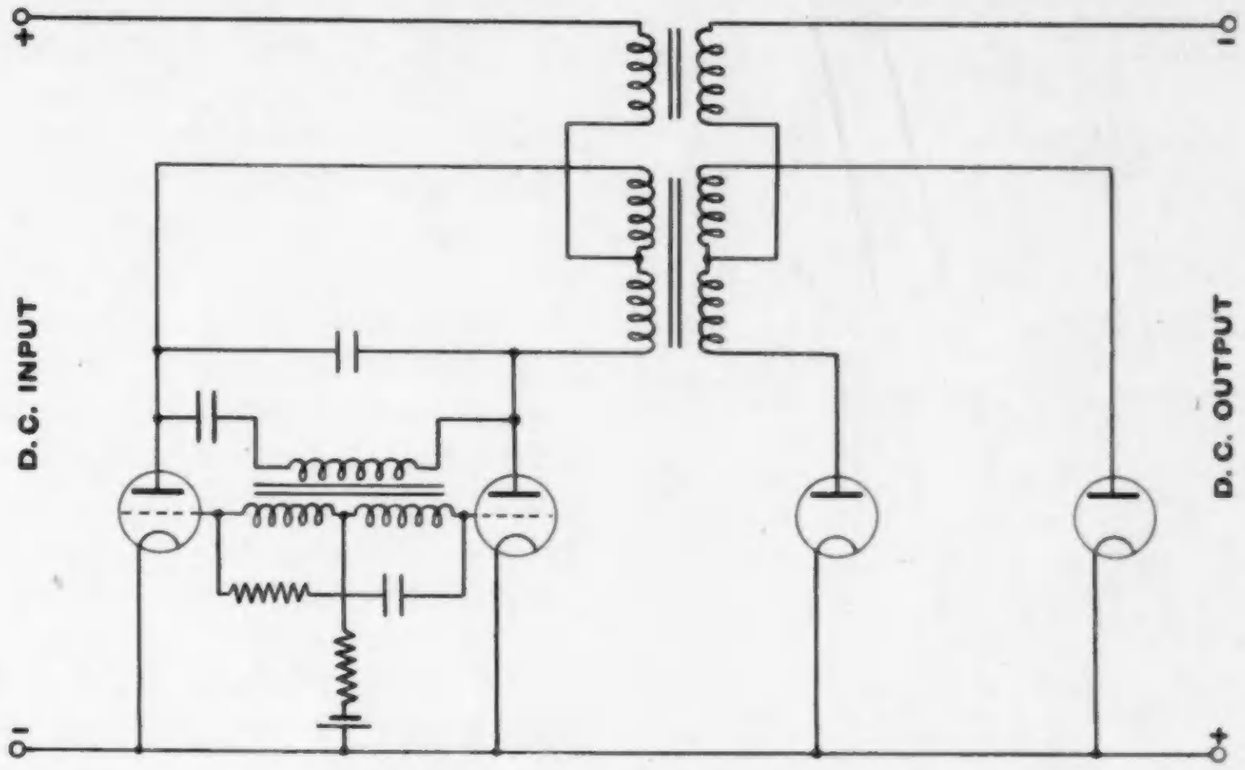


Fig. 24.—D.C. voltage transformer.

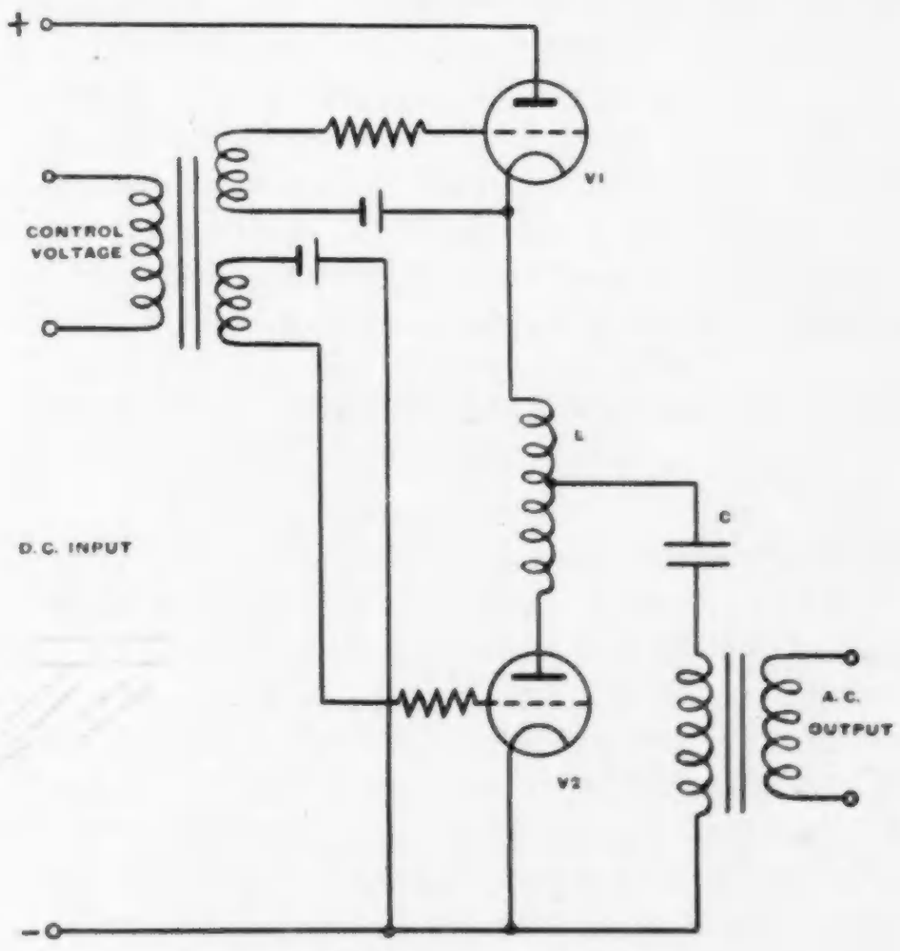


Fig. 25.—Series type inverter.

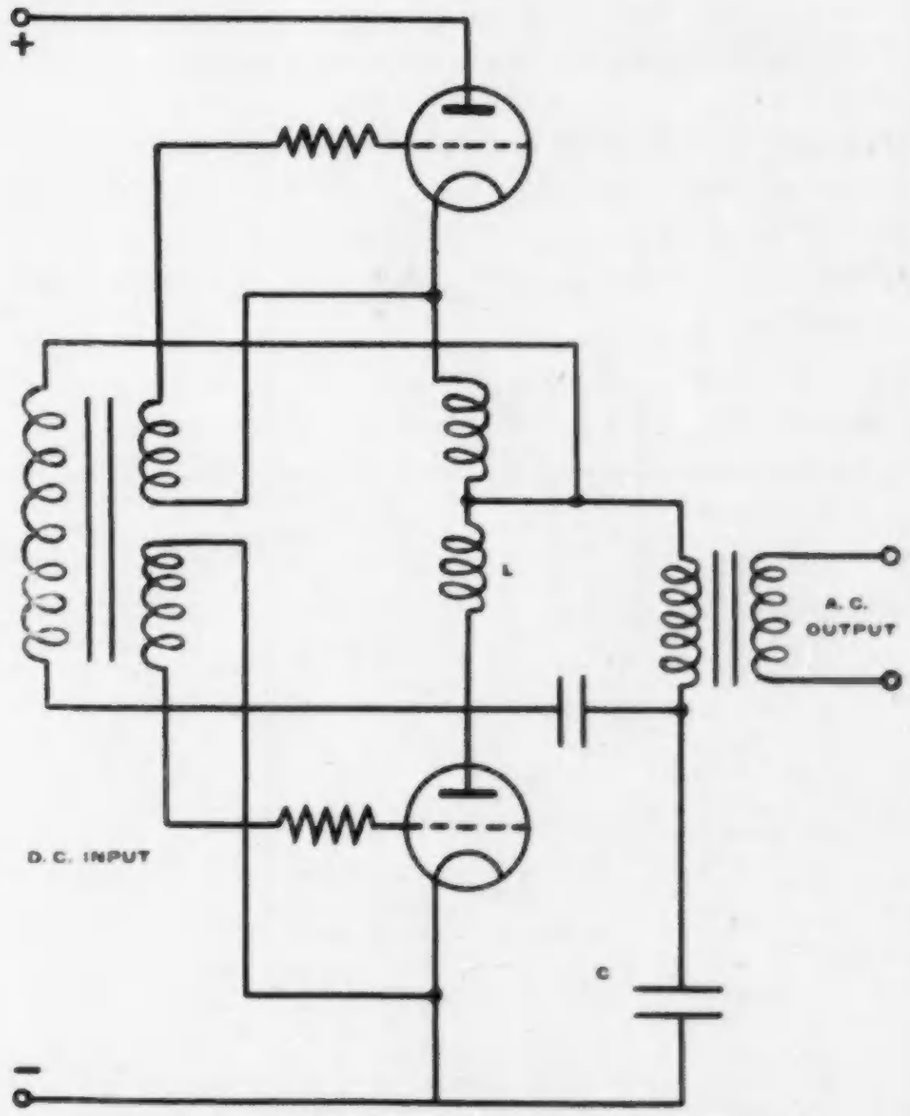


Fig. 26.—Self-excited series type inverter.

As the emission from mercury pool cathodes is

unlimited, the capacity of such circuits is only restricted by the general temperature rise of the discharge vessel, an excessive temperature causing a reduction in the permissible working voltage, by lowering the arcing potential between anode and

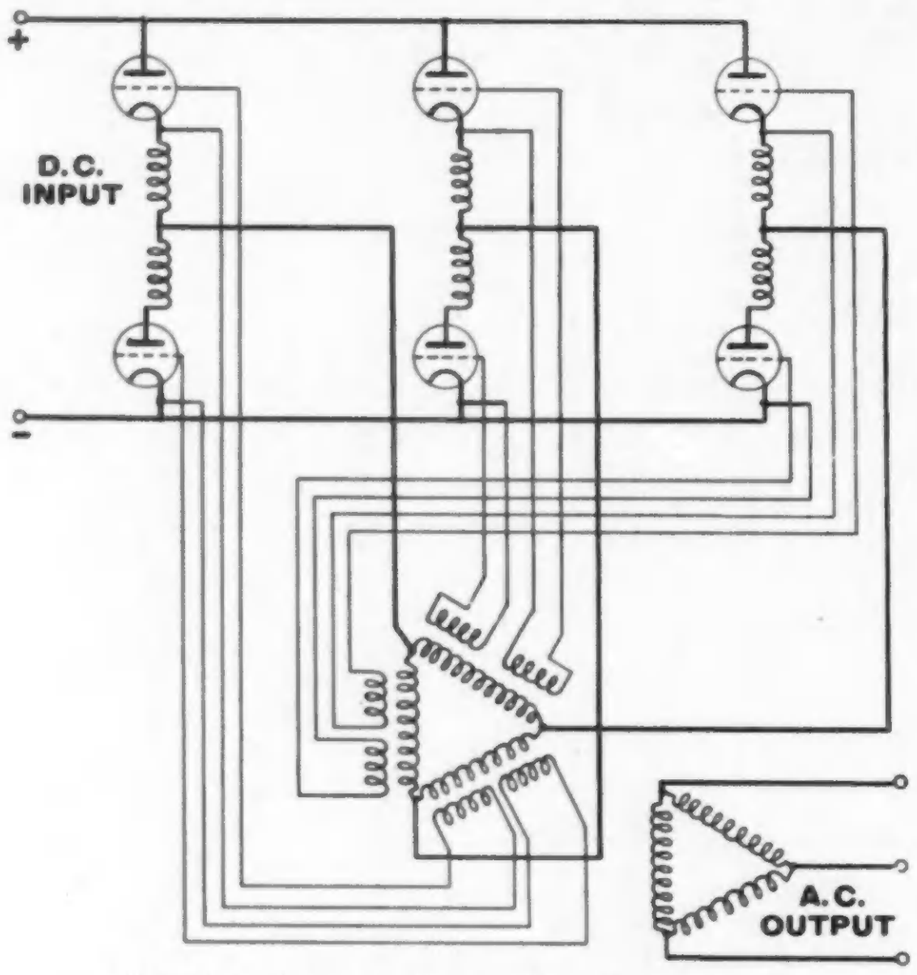


Fig. 27.—Three phase series type inverter.

cathode in the reverse direction. Currents of the order of 600 amperes per anode are available, so that a six phase inverter of this type employing a vessel with twelve anodes could supply about 20,000 kilowatts.

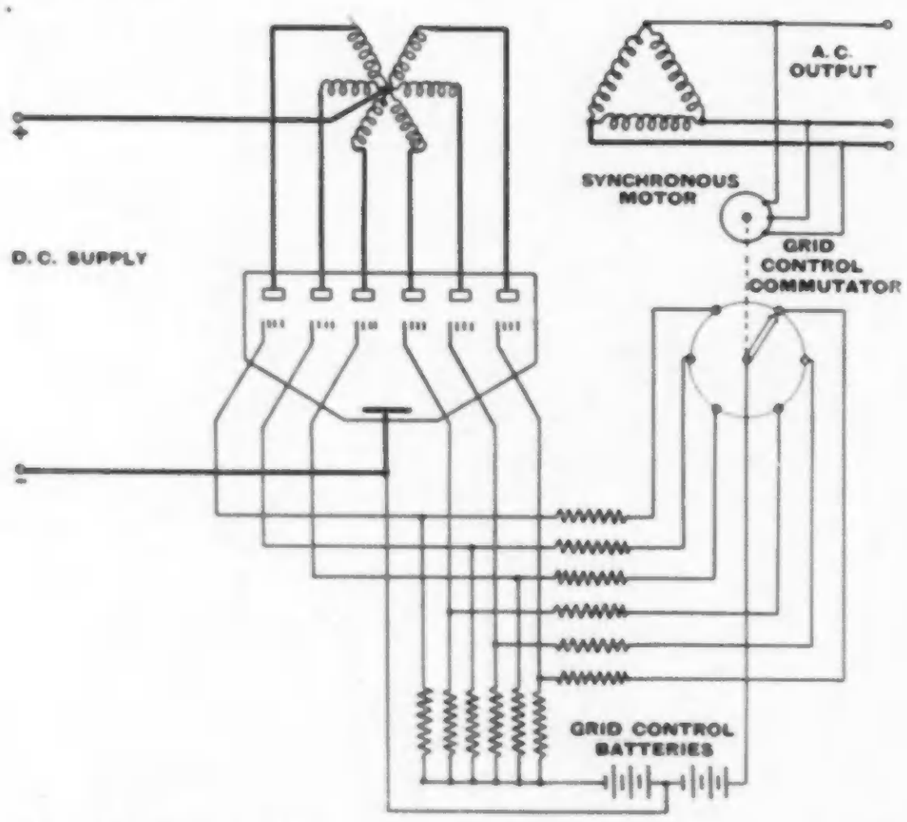


Fig. 28.—Large inverter, employing a mercury vapour discharge vessel with a mercury pool anode.

APPLICATIONS OF INVERTERS TO D.C. POWER TRANSMISSION.

The development of the inverter makes feasible the transmission of power by direct current over long distances. It is well known that direct current possesses several advantages over alternating for power transmission. For a given insulation of the line, the permissible working voltage is 1.4 times greater for D.C. than for A.C., and the capacity of the line correspondingly greater. The number of conductors required by a D.C. system is usually less than for an A.C. system, and the cost of construction for lines of equal capacity is therefore in the ratio of 1 to 2 approximately. Moreover, A.C. systems suffer from power losses due to out-of-phase currents, dielectric hysteresis and eddy currents, and have greater corona loss than D.C. Hitherto D.C. systems have not been greatly used, owing to the difficulty of constructing machines to work at sufficiently high D.C. voltages. The mercury vapour rectifier, however, and the inverter, provide cheap and efficient means of supplying high voltage D.C. and of reconverting it into suitable voltages for distribution to consumers.

A further advantage which may be obtained from the use of gasfilled relays in power transmission lies in their flexibility of operation. By suitable arrangement of the grid control, inverters can be made to work efficiently in the reverse direction also, taking power from the A.C. circuit, and feeding the D.C. circuit. The inverter thus provides a link between D.C. and A.C circuits through which power will pass in either direction, according to the relation of supply and demand on the two circuits. Two or more power stations, generating A.C. and supplying it to their local consumers, may therefore be connected by a D.C. network. The inverters enable power to travel in the D.C. network in either direction as the loads demand, and stations may close down or start up without the necessity for accurate synchronisation.

THE USE OF GASFILLED RELAYS IN TRACTION.

Besides their use as inverters and rectifiers proper, gasfilled relays, especially those of the mercury pool cathode type, have been used for the purpose of directly feeding the armatures of electric traction motors. A motor driven from a D.C. supply, with the gasfilled relay performing the functions of commutator and controller, is shown in fig. 29. In fig. 30 the motor is driven from a single phase A.C. supply, where the gasfilled relay has the additional function of rectification. The use of gasfilled relays in working motors from A.C. supplies results in a much improved speed characteristic.

THE GASFILLED RELAY WITH ALTERNATING ANODE SUPPLY.

When an alternating current supply is used to feed the anode circuit, the gasfilled relay possesses all the characteristics of the gas-discharge rectifier, with the addition of the property that the conduction

of the tube is controllable by the grid. During each positive half-cycle of the anode supply voltage, current *may* pass between anode and cathode; during the succeeding negative half-cycle this current is extinguished. During each negative half-cycle any ionisation present in the tube disperses (provided the supply frequency is low enough to allow sufficient time). At the beginning of each positive half-cycle, therefore, the grid has control over the discharge, and by the bias applied to the grid, the point in the positive half-cycle at which the discharge will start may be determined. A sufficiently high negative bias withholds the discharge altogether. Thus, when the average rectified current delivered by the tube is considered, it is seen that its value is controllable by the applied grid bias.

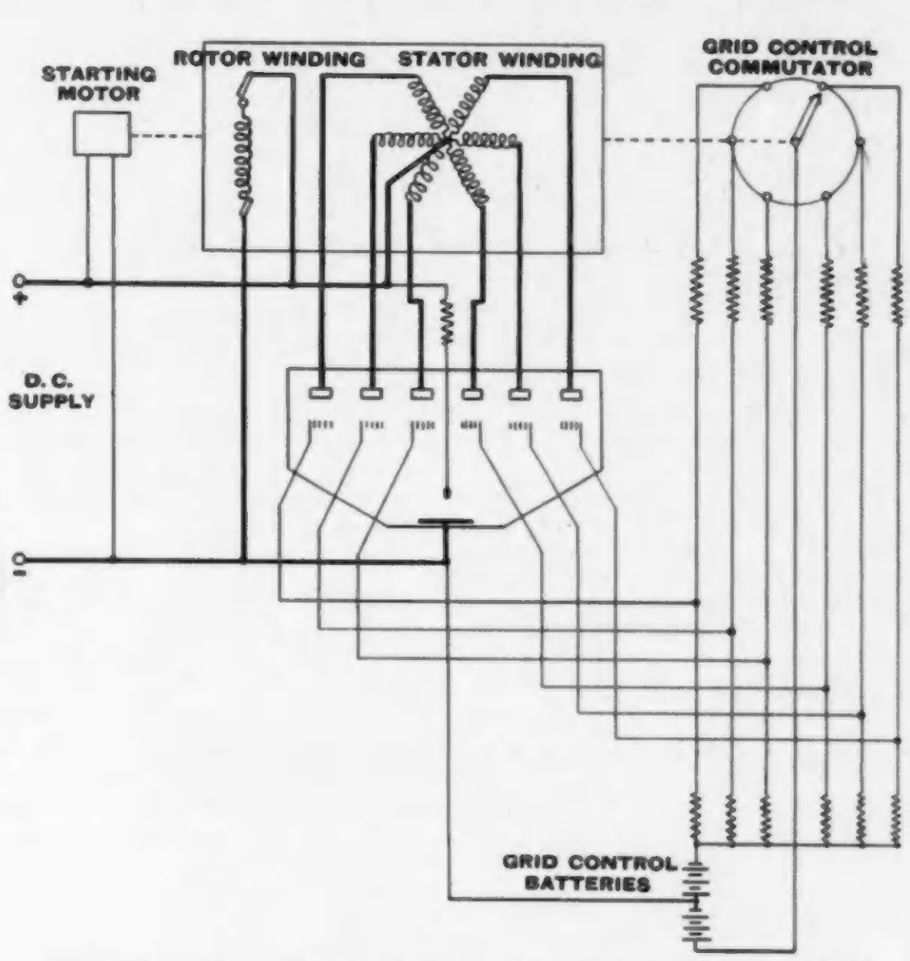


Fig. 29.—Commutatorless motor driven from a D.C. supply.

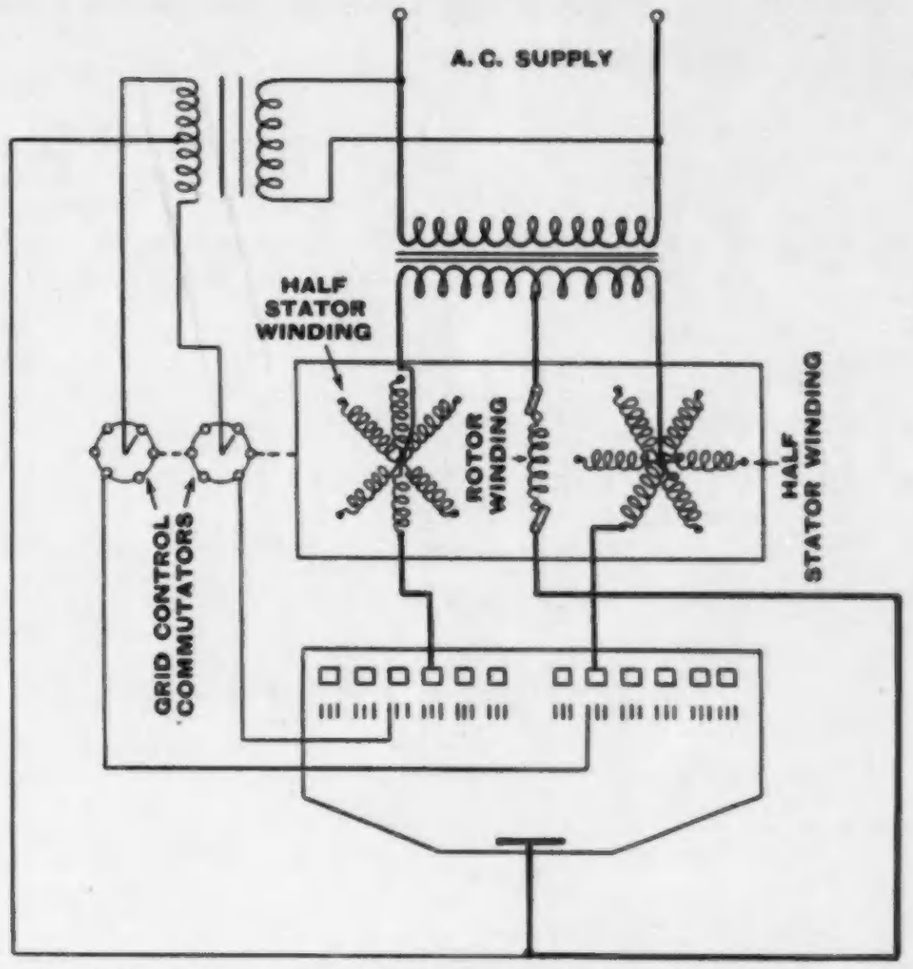


Fig. 30.—Commutatorless motor driven from an A.C. supply.

If the bias be reduced to a value equal to the peak of the critical grid voltage curve, current will flow for one quarter cycle as at *B*. As the bias is still further reduced, the discharge occupies correspondingly greater portions of the half-cycle, until at zero bias, current flows for the whole half-cycle as at *C*. Thus by the application of a steady bias to the grid, the mean anode current may be varied from a maximum value corresponding to full half-wave rectification, down to half that value, and thence discontinuously to zero. It is to be noted that for resistance loads the instantaneous value of the anode current is dependent only on the resistance of the load and upon the instantaneous value of the anode voltage, but the average current depends upon the instant of striking, that is, upon the impressed grid bias. In the case of reactive loads, the instantaneous anode current is governed to some extent by the instant of striking, and, moreover, the discharge may continue into the negative half-cycle for a period depending on the angle of the load. The mean load current, however, is still governed by the impressed grid bias. In most

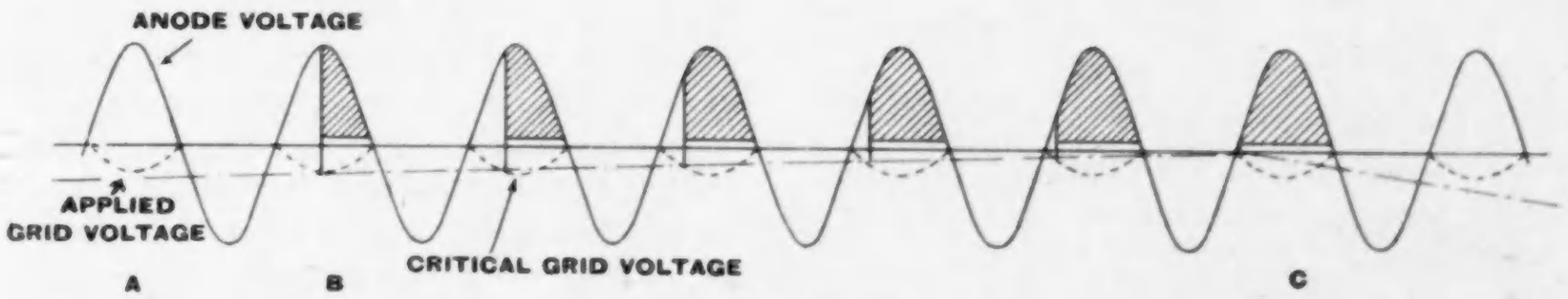


Fig. 31.—Grid control with alternating anode supply; effect of a steady bias of variable magnitude.

The case where a slowly varying bias is applied to the grid is illustrated in fig. 31. The sinusoidal curve represents the anode voltage, the dotted curve represents the critical grid voltage for the instantaneous value of the anode voltage, and the passage of anode current is denoted by the shaded regions. Current begins to flow during each positive half-cycle at the instant when the applied grid voltage is *first* more positive than the critical grid voltage, and continues to flow for the remainder

applications it is the average rectified current, rather than the instantaneous value, which is of chief interest ; especially so in inductive circuits where considerable smoothing of wave form takes place. This does not imply, of course, that the instantaneous value of the anode current may be disregarded. It is still necessary to ensure that the peak rating of the cathode emission is not exceeded.

Thus it is seen that under these conditions the gasfilled relay acts as a rectifier in which the output

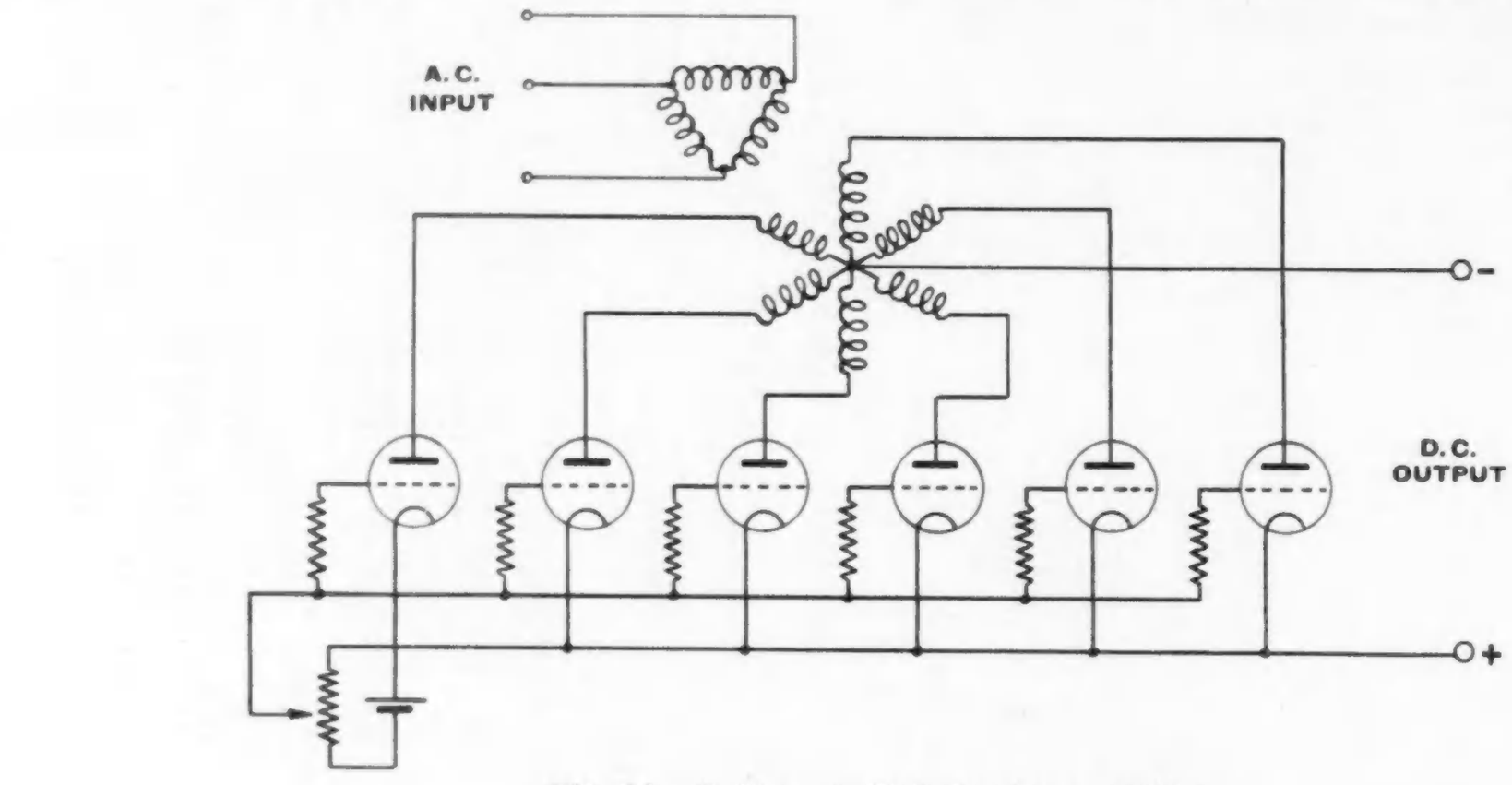


Fig. 32.—Grid controlled six-phase rectifier.

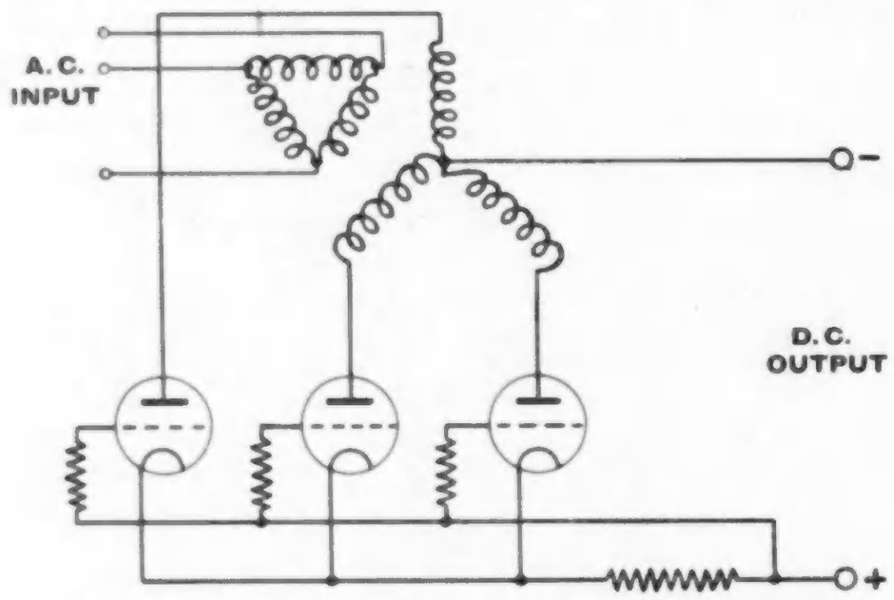


Fig. 33.—Automatically compensated rectifier for supplying D.C. at constant voltage.

may be varied continuously between its full and half values, or totally interrupted. An application of this method of control is in the regulation of the output voltage of a rectifier. A circuit diagram of the arrangement is shown in fig. 32. The rectifier may consist of a number of gasfilled relays, one or more for each phase of the A.C. supply, or it may be of the mercury pool cathode type with several anodes, with their respective controlling grids. The rectified D.C. output is switched on and off, and its voltage may be controlled by adjustment of the grid bias. By feeding the grids from a resistance connected in the output circuit as in fig. 33, a negative bias proportional to the output current is impressed on the grids. It can be arranged that the variation of bias due to variation of output current controls the rectifier so that the output voltage is constant, independent of the load. It can similarly be arranged that, by this method, the operation of the rectifier will be interrupted should the output current become excessive. The use of grids in vessels containing more than one anode also provides a means of clearing back-fires (discharges between anode or cathode in the reverse direction) and cross-fires (discharges between two anodes). Upon the occurrence of an objectionable discharge of this nature, a relay operates and charges negatively the corresponding grid or grids with the result that the discharge is extinguished within the cycle.

CONTROL WITH ALTERNATING GRID VOLTAGE.

When an alternating voltage of phase opposite to that of the anode supply is impressed on the grid of a gas-filled relay, see fig. 34, anode current either flows throughout the whole of the positive half-cycles of the anode voltage or is totally withheld, according to the amplitude of the grid voltage applied. As the grid voltage is reduced in amplitude, the average rectified current passing through the tube changes abruptly from zero to its maximum value, when the ratio of anode to grid voltage exceeds μ, the "grid control ratio." If the phase of the grid voltage be advanced slightly from opposition with the anode supply, say by 30 degrees as shown in fig. 35, the change of average rectified current with the amplitude of impressed grid voltage loses its abrupt nature, and becomes a gradual variation as is illustrated in the figure.

Two examples of the use of this method of controlling the anode current, by variation of the amplitude of an alternating grid potential are shown in figs. 36 and 37. In fig. 36 a gasfilled relay is used to maintain a furnace at a constant temperature. A bridge circuit, one element of which is a resistance thermometer enclosed in the furnace, governs the magnitude of the potential impressed on the grid of the gasfilled relay. When the temperature of the furnace is at the required point, or too high, the amplitude of grid voltage is sufficient to withhold the discharge. If the furnace cools below the required temperature, the bridge approaches nearer to its balanced condition, and anode current is permitted to flow until the correct temperature is regained. The anode current may be used directly in heating the furnace, or alternatively to operate a contactor in the heating circuit.

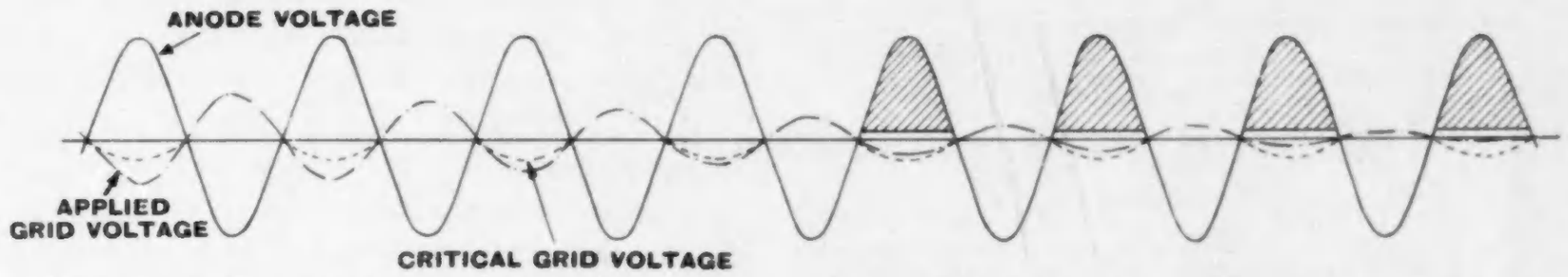


Fig. 34.—Grid control with alternating anode supply; effect of an alternating grid potential of opposite phase and of variable amplitude.

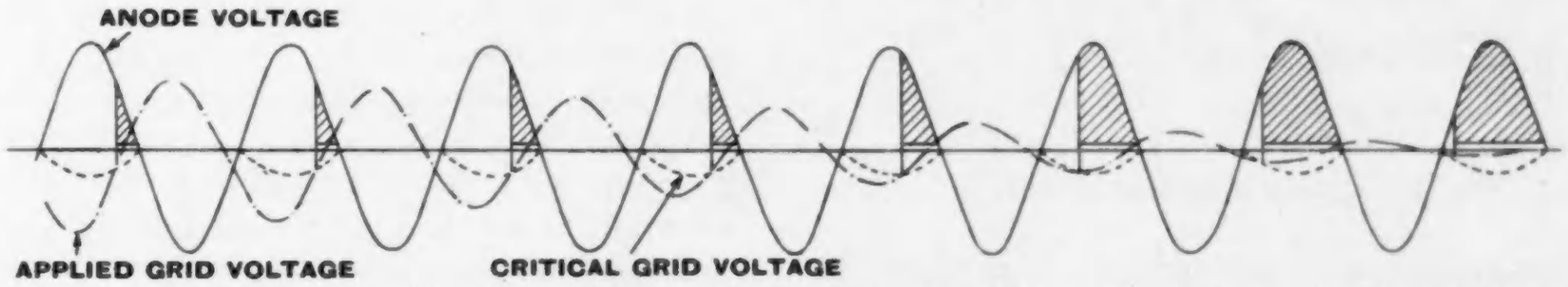


Fig. 35.—Grid control with alternating anode supply; effect of an alternating grid potential of variable amplitude, 150° out of phase with the anode.

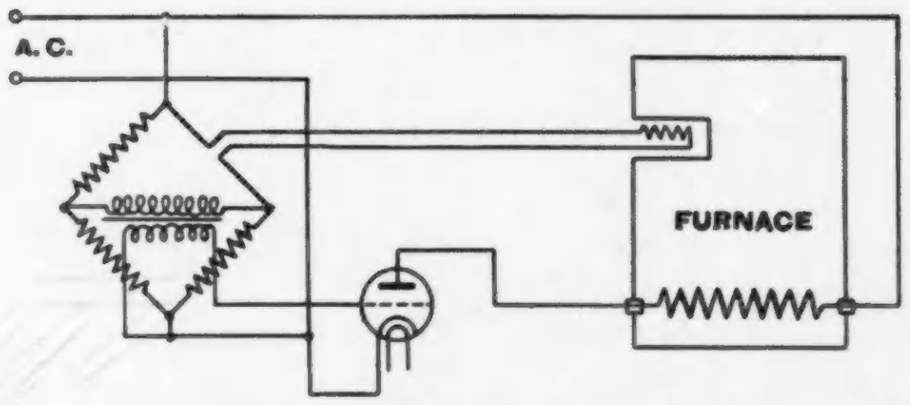


Fig. 36.—Use of a gasfilled relay to maintain constant temperature in a furnace.

In the second arrangement shown in fig. 37 the phase of the grid voltage applied is advanced by a constant small angle from opposition with the anode supply by means of the condenser C_1, and its amplitude is adjustable by means of the potentiometer P. By this means the rectified anode current can be continuously varied from a very small value, to a maximum value corresponding to half wave rectification. The practical applications of a circuit of this type are obviously very numerous, as, for instance, the precise control of the speed of a D.C. motor, or of the voltage of a generator, by variation of field excitation. Where larger currents are required, or smoothness of wave form is of importance, a polyphase circuit employing several gasfilled relays may be used.

By the addition of a saturable cored choke, the circuit of fig. 37 may also be used for controlling alternating current. The rectified output from the gasfilled relays is made to saturate the iron core of the choke to a variable extent and so reduce the impedance of the A.C. winding. The use of this

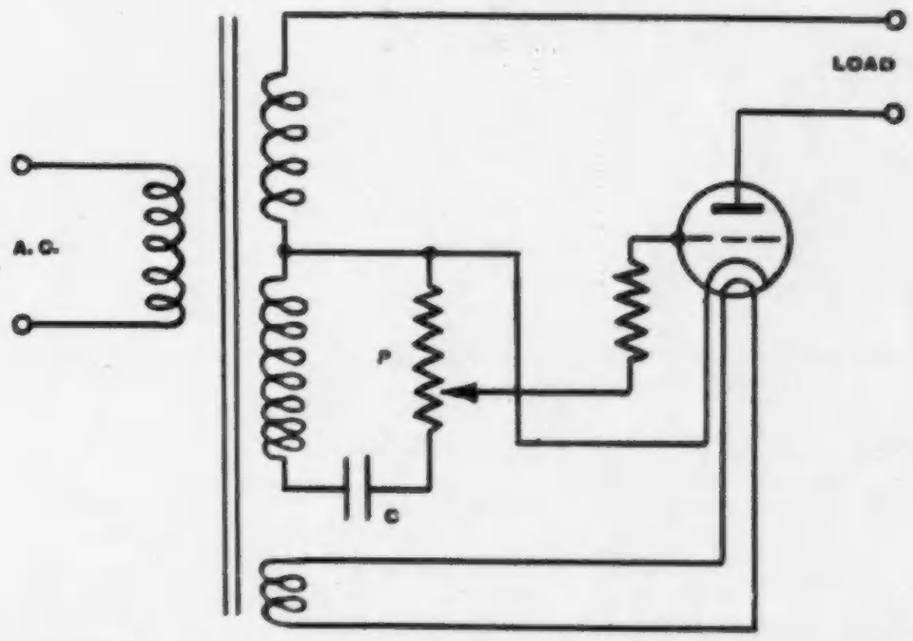


Fig. 37.—Anode current control by variation of grid voltage amplitude.

device results in a considerable magnification of the amount of power which a single tube can control. For instance, one Osram G.T.1 gasfilled relay, with an anode supply of 240 volts, actually consuming about 80 watts, can by the use of a saturable core control about 800 watts of A.C. power. In fig. 38 is shown a typical example of the use of a saturable core reactor for controlling the illumination of a bank of lamps, applicable, for instance, to stage lighting or lamp dimming in theatres.

PHASE-CONTROL.

A third and ingenious method, due to Toulon,* of controlling the duration of the discharge is by altering the phase relationship between the alternating voltage applied to the grid and that of the anode supply. When the phase difference is 180°

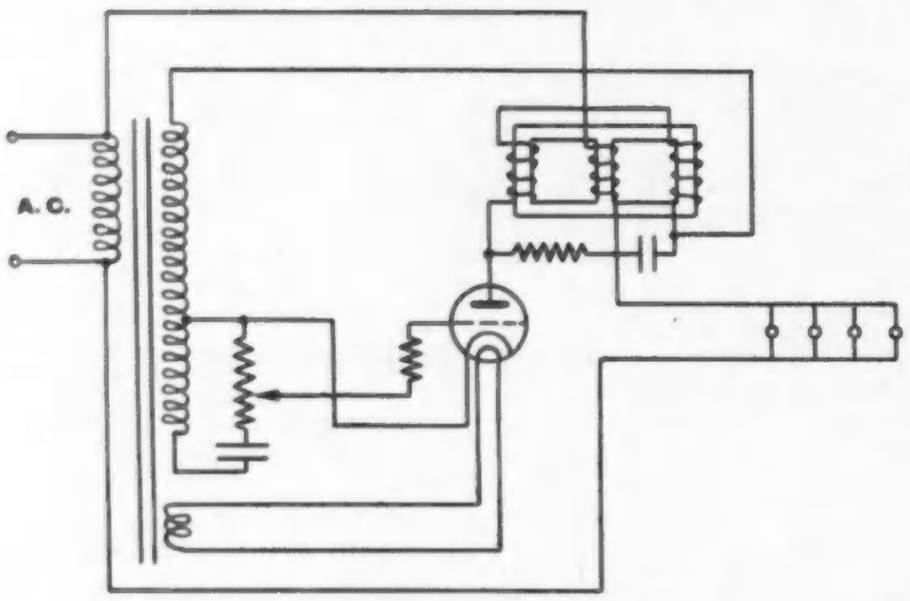


Fig. 38.—Lamp dimming circuit.

anode current is totally withheld; this is shown in fig. 39(a), while figs. 39(b), (c), (d), (e), (f) and (g) show the effect of advancing the grid phase by progressive amounts. The curves show that the average anode current steadily increases as the phase is advanced until, in fig. 39(g), where the grid and anode voltages are in phase, the current is at its maximum. In fig. 39(h) the grid phase has been retarded from opposition by a small angle, and it will be noticed that the anode current has its maximum value. Thus it is seen that, starting from the case where the anode and grid phases are directly opposite, and no anode current flows, by advancing the grid phase progressively through 180°, the average anode current is gradually increased, and by retarding the grid phase the average anode current *immediately* attains full value. Phase-control provides a convenient method of controlling the output of rectifiers. For large installations, excitation voltages for the several grids can be obtained from as many windings of a polyphase transformer in which the secondaries can be rotated with respect to the primaries. In smaller circuits, containing only one or two tubes, it is more convenient to make use of resistive and reactive networks for varying the phase of the grid supply. Fig. 40 gives three such circuits, together with diagrams showing the relationship between the anode and grid voltage vectors. Three types of control are available: in fig. 40(a), the anode current increases steadily as the resistance is increased; in fig. 40(b) anode current decreases steadily as the resistance is increased; whilst in fig. 40(c) the anode current is at a maximum or zero value according as the resistance be greater or less than a certain value.

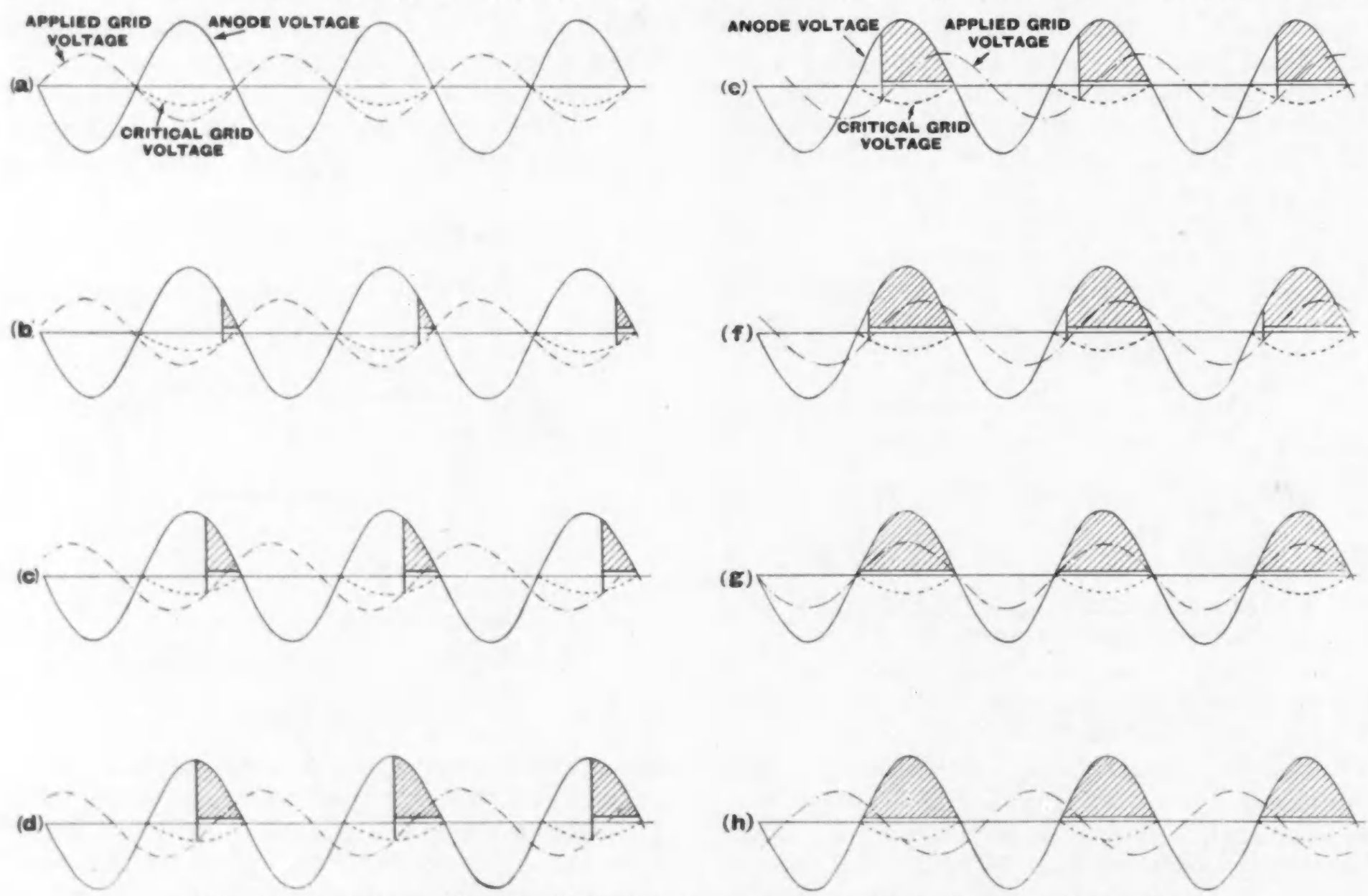


Fig. 39.—Grid control with alternating anode supply; effect of varying the relative phases of the grid and anode voltages.

* Brit. Pat. 209426.

Phase control is readily adapted for many purposes, especially automatic regulation, where the advantage of a continuously variable output from the gasfilled relay is of considerable use in providing smooth regulation and preventing hunting. The control of the speed of a D.C. motor used for reeling wire, whereby the tension of the wire is kept uniform, irrespective of the growing dimensions of the bobbin, is illustrated in fig. 41. The rectified output from a gasfilled relay supplies the field winding (or portion of the field winding) and its value is controlled by a movable core inductance which alters the grid phase. The movable core can slide vertically within the choke and is suspended on a loop of the wire which is being reeled. Thus if the tension of the wire is reduced so that the core sinks further into the choke, increasing the inductance, the grid phase is thereby retarded, and the field current of the motor is reduced, so that motor speed is increased. When the wire becomes too tight, the motor speed is similarly reduced.

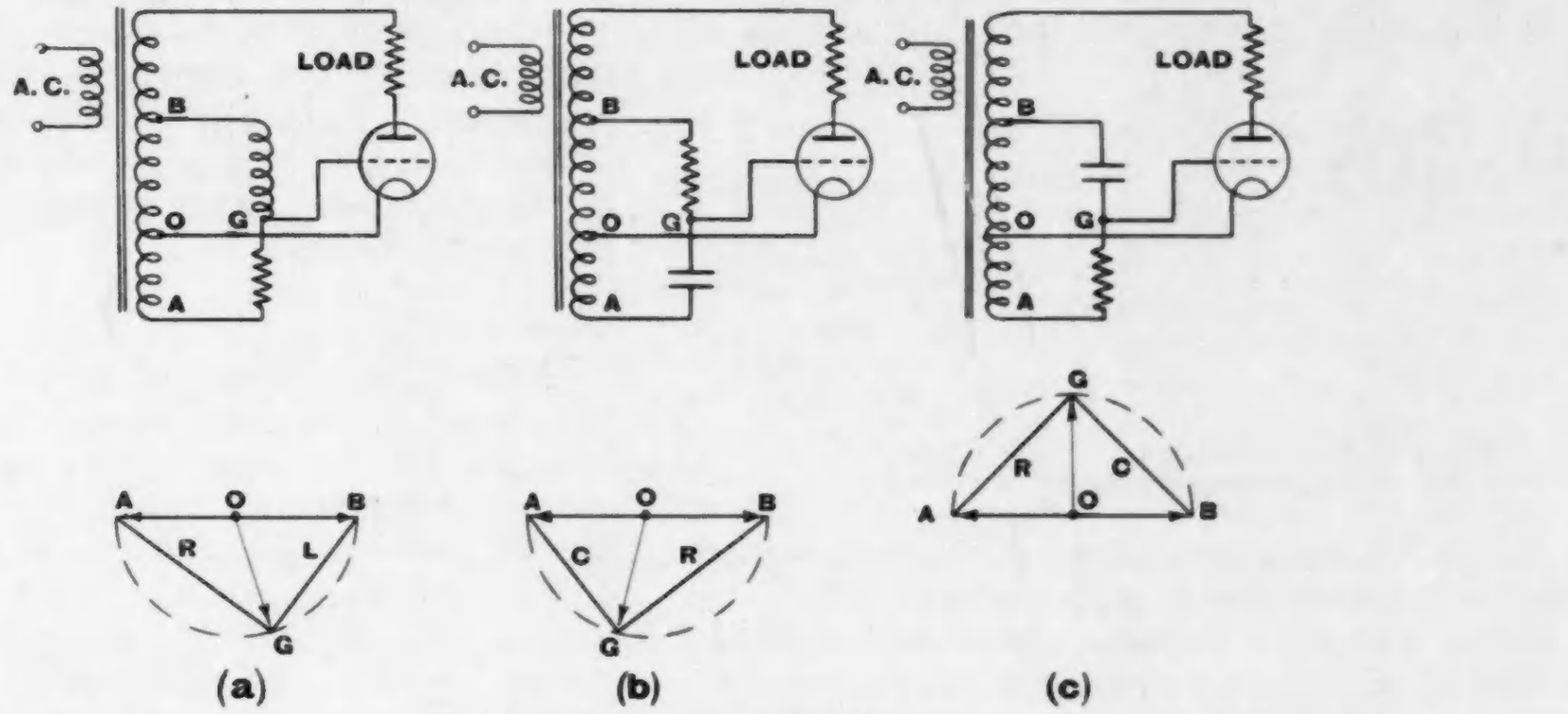


Fig. 40.—Phase control circuits.

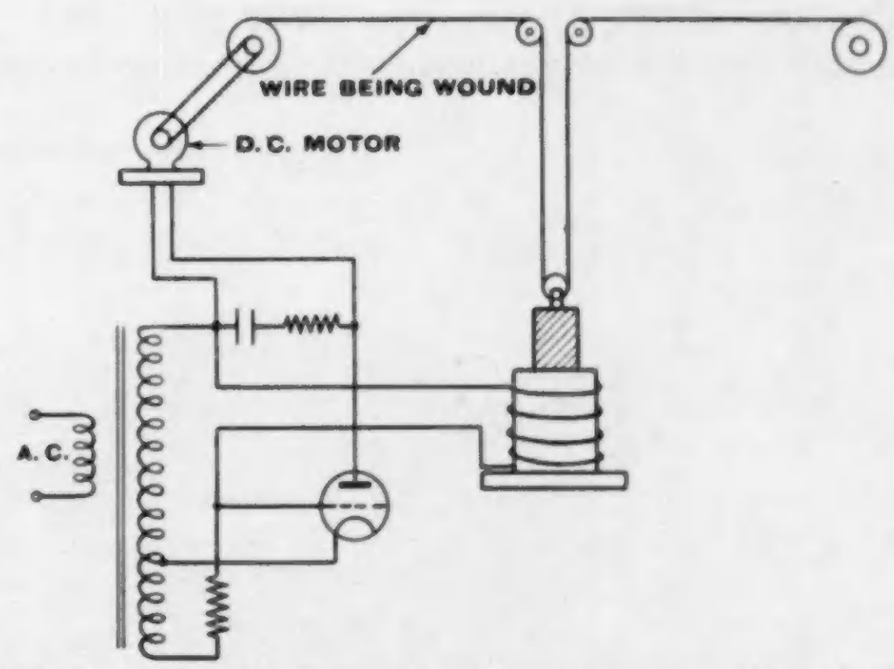


Fig. 41.—Tension regulation for wire winding machine by phase control of a gasfilled relay.

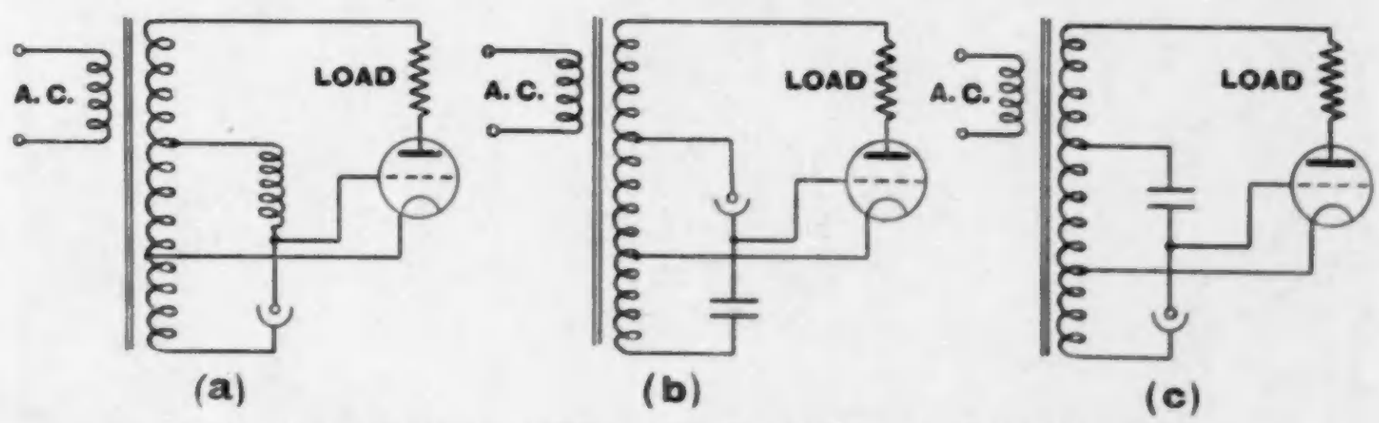


Fig. 42.—Phase control circuits employing photoelectric cells.

PHOTOCELLS AND GASFILLED RELAYS.

As further examples of phase-control, the controlling of a gasfilled relay by means of a light-sensitive cell will be considered. As already stated, the power required by the grid of a gasfilled relay, in governing the anode current is extremely small, so that photoelectric cells are well suited for use in the grid circuit of even the larger types of gasfilled relays without intermediate amplification. The combination of the two tubes forms a relay operated by light, giving large current outputs, having no moving parts and capable of innumerable applications.

Three types of phase control circuit employing light sensitive cells are shown in fig. 42. If selenium cells be used (the resistance of selium decreases with increasing intensity of illumination) then it will be seen that these circuits are the exact counter-

parts of those of fig. 40. In fig. 42(a), the output of the gasfilled relay changes progressively as the intensity of illumination is changed, the output decreasing as the light is increased and *vice versa*. In fig. 42(b) the output increases or decreases progressively in accordance with increase or decrease in illumination. In fig. 42(c) the output is either at

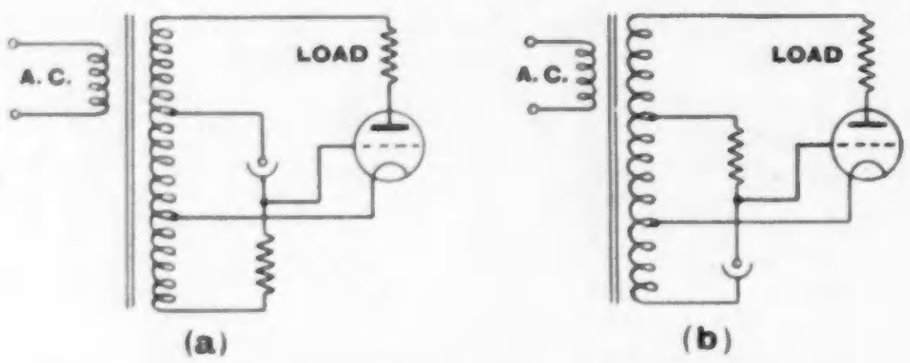


Fig. 43.—Grid voltage amplitude control circuits employing photoelectric cells.

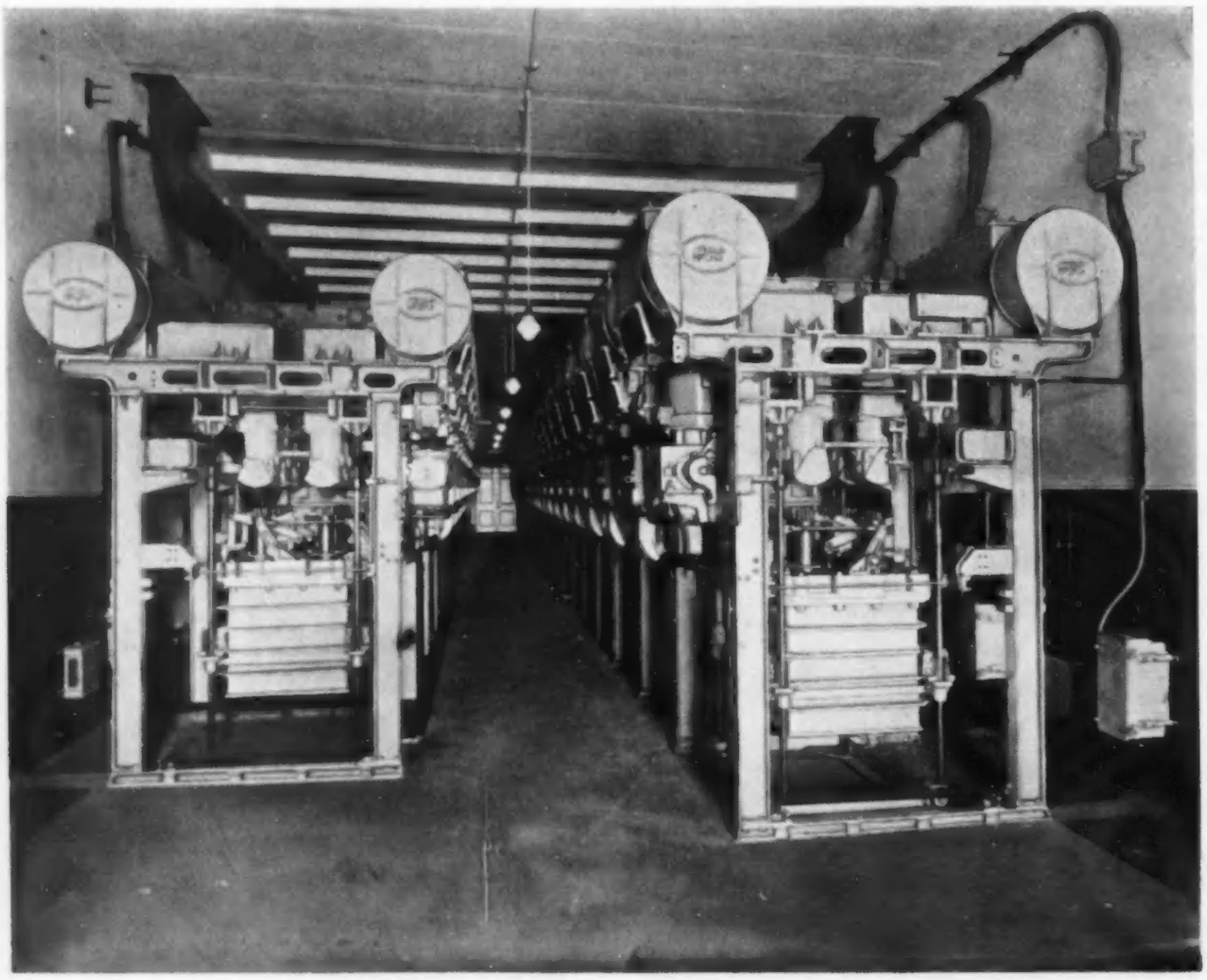
maximum value or zero, according as the illumination is less or greater than a certain amount. When cells of the photoelectric emission type are employed, these circuits give the same results in practice, but the principle of their operation is slightly different. In this type of cell current only passes in one direction—electrons may pass from the photo-electric cathode to the anode, their number being dependent on the amount of light reaching the cathode. Hence on A.C. supplies, current only passes under the control of light during alternate half-cycles. The operation of the gasfilled relay is therefore due to a distortion of the wave form of the grid potential rather than to a change of its phase.

In fig. 43 are given the circuits of two combinations in which light controls the amplitude of the grid potential. In fig. 43(a) the output is at maximum value or zero, according as the illumination is greater or less than a certain amount, and in fig. 43(b) the reverse conditions hold.

CONCLUSION.

Although the principle of the gasfilled relay has been known for a number of years, its development in a practical form is comparatively recent. The variety of applications which have been described here are sufficient to indicate the widespread utility of the gasfilled relay in all branches of electrical science and engineering. Its capabilities have already been successfully demonstrated, and there is little doubt that it will soon take its place with other devices such as the vacuum thermionic valve and the mercury vapour rectifier as a standard piece of electrical equipment.

Metal-clad Switchgear for Glasgow Corporation Tramways.



General view of G.E.C. 6,600-volt, 350,000 kVA metal-clad switchgear installed in the Pinkston power station of the Glasgow Corporation Tramways. The remote control board is shown in the frontispiece of this issue.

The New High Tension Power Transmission Scheme at Worksop.

By V. F. ELLISON,
G.E.C. Resident Engineer, Sheffield.

The high tension distribution system of the Worksop Corporation, which covers a considerable area of Nottinghamshire, presents many interesting features, especially with regard to the method of transformer tap-changing at the various kiosk sub-stations by remote supervisory control from the Corporation's Electricity Works.

While it is believed that this is the first instance in which remote supervisory control has been applied to kiosks, the system developed for the purpose promises to have a very wide application.

HISTORICAL.

THE electricity undertaking of the Worksop Corporation was inaugurated in 1901, when a direct current supply was given to the town by the installation of three steam driven generators. As the demand increased, further plant of the same type was installed, but, in 1921, it was realised that fresh provision would have to be made if an adequate supply were to be maintained in the district. An agreement was therefore reached with Manton Colliery (where two turbo-alternators were installed), for a bulk supply of alternating current to be taken from the colliery and converted by a 500 kW rotary converter in the Corporation's power house. The demand still increased, however, and the existing steam reciprocating sets were augmented by the addition of two Diesel engine driven generators.

Following the introduction of the Electricity Supply Act in 1926, the Worksop area of supply was extended, and eventually in 1930 the electricity system was linked up with that of the Derby and Notts Power Co. With the question of power supply arranged on a satisfactory basis, the next problem was that of efficient distribution. It should be appreciated that the area extends 9½ miles east to west, with an average width of some 4 miles, and the boundary is very irregular. The problems of distribution were, therefore, not easy, and the fact that there exists to-day an exceedingly efficient system, is evidence of much care and foresight in deciding upon the methods to be adopted. It is significant that the load factor has been increased from 25.5 in 1927 to 31.35 in 1932, while the output for the corresponding period has been increased by 72.1 per cent.

The two sources of supply—the Derby and Notts Power Co. at 11,000 volts and Manton Colliery at 500 volts—are linked together at Manton Main sub-station, which may be regarded as the starting point of the ring main system of feeding adopted.

It must be realised at the outset that, in the area under discussion, high tension distribution is carried out at two different voltages. These are the new 11,000-volt overhead transmission line, fig. 1, and

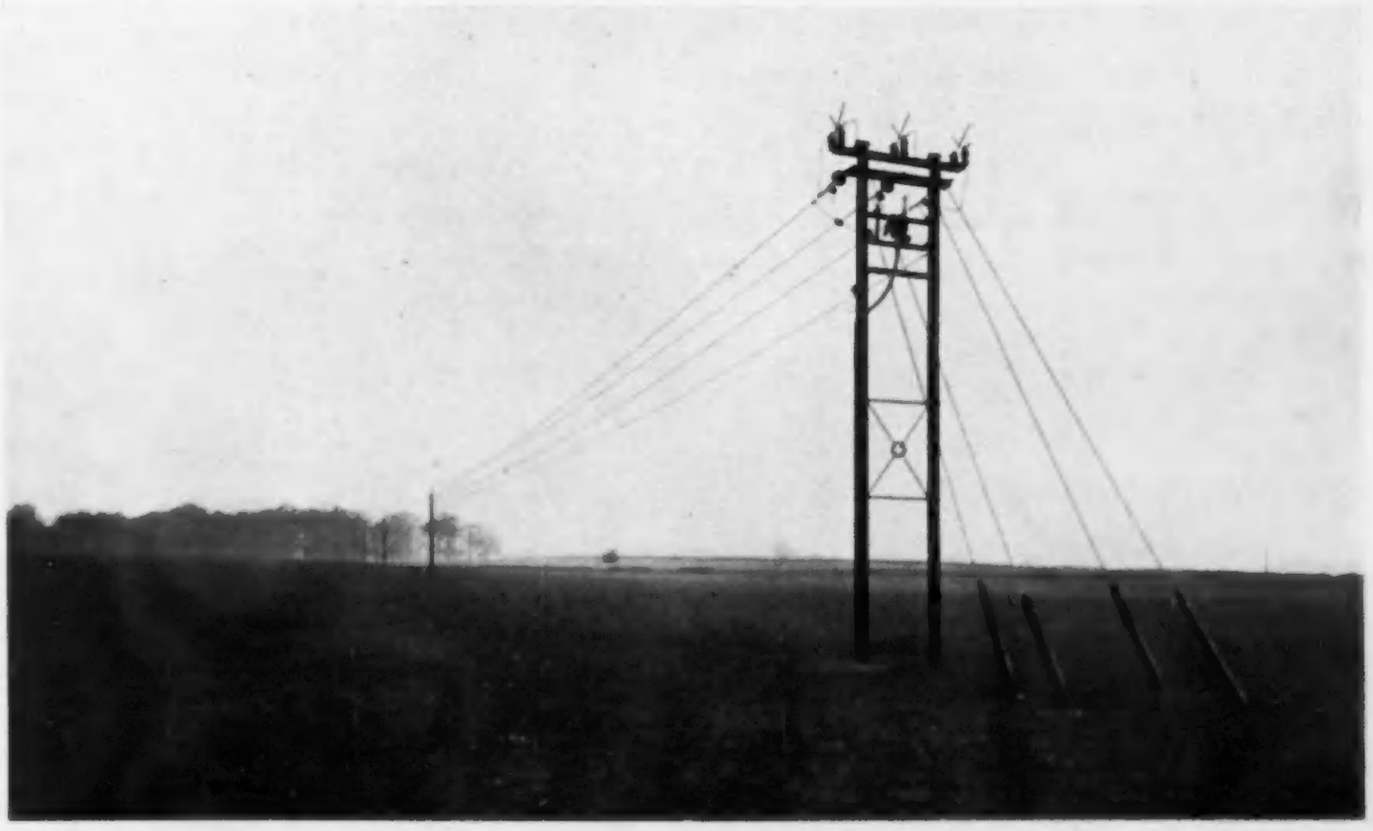


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Fig. 1.— Part of the 11,000-volt overhead transmission line.

the old 6,600-volt underground system, both of which form the ring main. Before describing the installation in detail, however, it will be better briefly to review the system as it now stands.

PRESENT SYSTEM OF DISTRIBUTION.

At Manton Main sub-station, transformers and switchgear are installed to link up the 11,000-volt and 500-volt incoming supplies previously mentioned and also to provide for the 11,000-volt and 6,600-volt outgoing feeders.

From Manton Main sub-station the ring main starts off in one direction for a distance of approximately seven miles in the form of an 11,000-volt, 3 phase, overhead line and is looped in and out of Sparken Hill sub-station and tapped off to Market Place sub-station. Feeders are also tapped off along the line at various points to supply Clumber Cottage, Worksop College, Steetley Quarry and Mansfield Road, the line terminating at Rhodesia sub-station.

Returning to Manton sub-station, the ring main starts off in the other direction in the form of a 6,600-volt underground cable, feeding into several sub-stations in the town, in addition to the Electricity Works, and terminating also at Rhodesia sub-station. At this point, transformers and switchgear are installed to link together the 11,000-volt overhead line and the 6,600-volt underground cable, thus completing the ring main.

It will be seen from the E.H.T. control diagram, fig. 2, that the 11,000-volt and 6,600-volt feeders are also interconnected between Sparken Hill and the Electricity Works through two sub-stations,

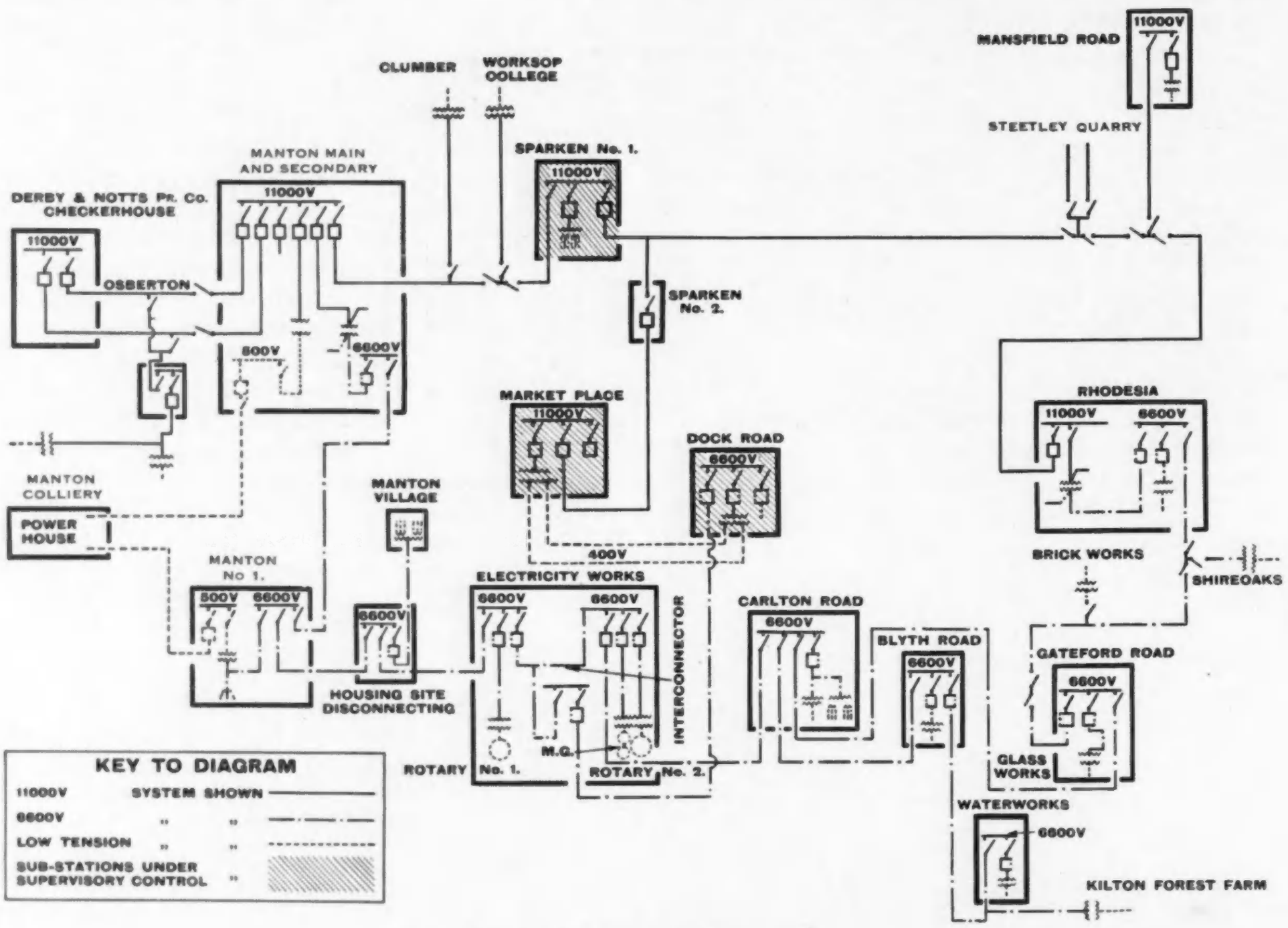

Fig. 2.—E.H.T. control diagram.

From Manton Main sub-station the ring main starts off in one direction for a distance of approximately seven miles in the form of an 11,000-volt, 3 phase, overhead line and is looped in and out of Sparken Hill sub-station and tapped off to Market Place sub-station. Feeders are also tapped off along the line at various points to supply Clumber Cottage, Worksop College, Steetley Quarry and Mansfield Road, the line terminating at Rhodesia sub-station.

Returning to Manton sub-station, the ring main starts off in the other direction in the form of a 6,600-volt underground cable, feeding into several sub-stations in the town, in addition to the Electricity Works, one at Market Place and the other at Dock Road. These three sub-stations are of a special kiosk type and are under remote supervisory control from the Electricity Works.

MANTON MAIN SUB-STATION.

The large kiosk forming Manton Main sub-station (seen on the right of fig. 3) possesses several features of interest as regards kiosk design. Measuring approximately 13 ft. long by 7½ ft. wide by 7½ ft. high it is equipped with six oil circuit breaker panels controlling two incoming and four outgoing feeders. Each of the incoming feeders is rated at 2,500 kVA and is taken direct to a 200 amp. oil circuit breaker fitted with overload and earth leakage

trips. Connections from the breakers are made to the busbars through 200 amp. isolating links. Of the four outgoing feeder panels (three of which are shown in fig. 4), one is a spare and the other three control the outgoing feeders to the 11,000-volt overhead line, the 6,600-volt network and the 500-volt interconnector to the power station at Manton Colliery. The latter feeder is coupled to the 11,000-volt supply through a 1,000 kVA, 3-phase, 50 cycle, outdoor type transformer, while the 6,600-volt supply is obtained from a 750 kVA transformer of similar design. Both of these transformers are situated close to the sub-station (see fig. 3).

All six panels are equipped with ammeters, while a power factor meter is provided and also a synchronoscope, by means of which the incoming and outgoing supplies may be synchronised, sockets being fitted for this purpose on each panel. The kiosk also houses the usual current and potential transformers, isolating links, high tension fuses and the like.

The panels are arranged three at each end of the kiosk, large double swing doors giving access to the front of the panels on which the oil circuit breaker handles and instruments are mounted. A feature of the construction of the kiosk itself is the provision of a "flapper cover" (fig. 4) which consists of a metal sheet hinged along the top of the kiosk and opening in an outward direction, affording protection against

Fig. 4.—H.T. control panels in Manton Main sub-station.

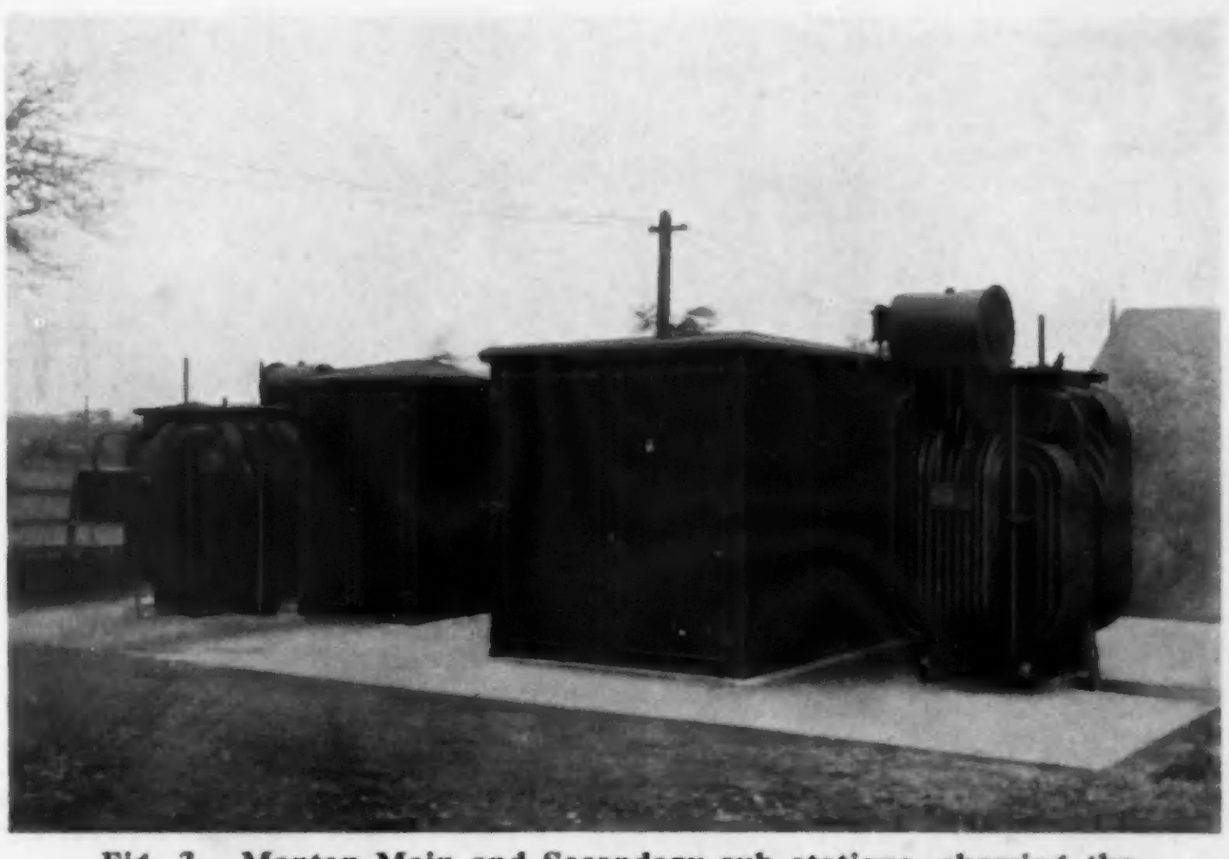

Fig. 3.—Manton Main and Secondary sub-stations, showing the 1,000 kVA and 750 kVA outdoor transformers.

rain and snow for the operator and equipment when the doors of the kiosk are opened.

A smaller kiosk, known as the Manton Secondary sub-station, is situated close to the main kiosk and houses two panels, one being equipped with control gear for the 500-volt interconnector to Manton Colliery and the other connecting the 6,600-volt supply to the Worksop Corporation's 6,600-volt mains. Two meters are provided, one registering the supply received from Manton Colliery and the other the supply to Manton. Reciprocal arrangements exist between the Colliery Company and the Corporation whereby in normal circumstances the Corporation receive a bulk supply of 600 kVA from the Colliery, and in an emergency this can be exceeded. In the event of a breakdown on the Colliery side, however, arrangements are made whereby the Colliery can receive a supply.

OVERHEAD TRANSMISSION LINE.

As previously indicated, the 11,000-volt line between Manton Main and Rhodesia sub-stations is carried overhead except in those instances where the line crosses railways, G.P.O. crossings and the like, where it is not possible to erect overhead conductors.

Wood poles are employed to carry the line, straight line poles being employed fitted with a cross arm, a construction which has been patented by the Pirelli-General Cable Works. The conductor used is 7/.166 inch steel-cored aluminium, while the under-running earth wire is of 7/12 S.W.G. "Grapo" galvanised stranded steel. Pin insulators are used for the straight lines and strain insulators at section

and angle points, the average span between poles being 250 feet. Where underground cable is necessary, three core, .04 sq. inch paper insulated, lead sheathed, double steel tape armoured and served cable is installed.

"Tee-off" tappings are arranged at certain points along the line for supplying power to villages, etc. Clumber Cottage, Worksop College, Steetley Quarry and Mansfield Road are supplied in this way and

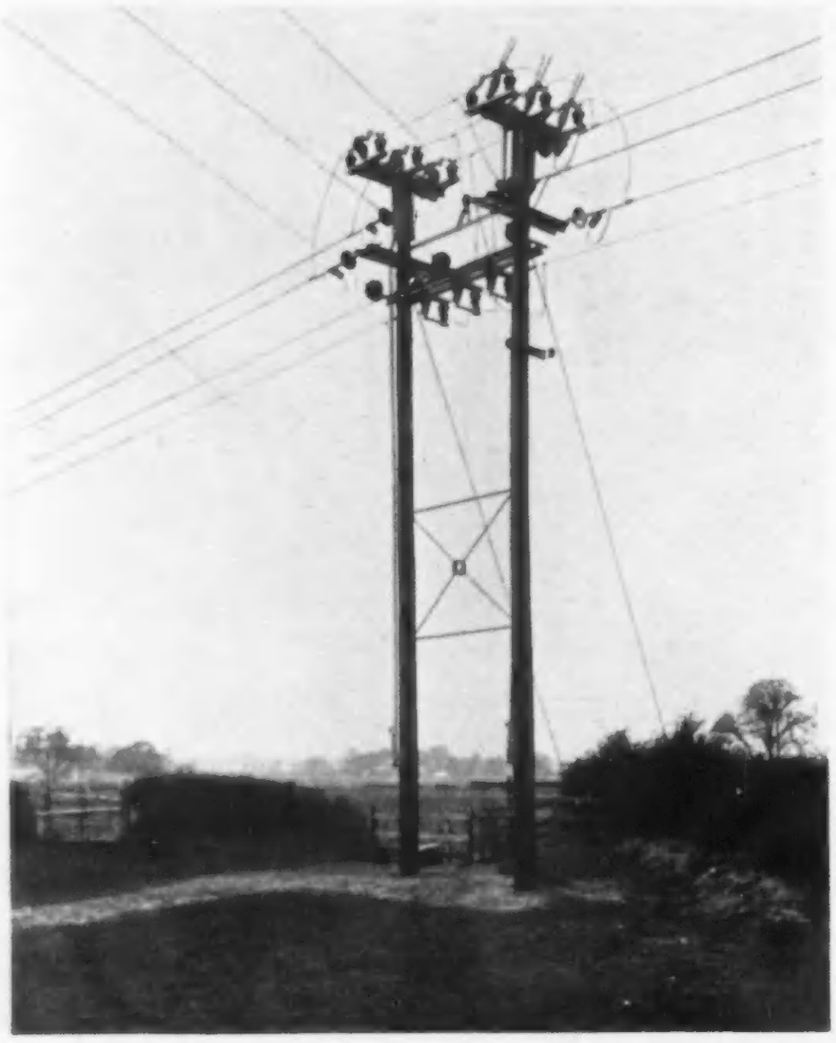

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Fig. 5.—One of the tee-off poles, equipped with horn type air-break switches and isolating links.

in each case, as the main line forms part of the ring main, the branch lines are connected at "H" poles equipped with two manually-operated air-break switches, fig. 5. These control the main line on either side of the branch line. Each junction is also provided with a set of inverted isolating links for disconnecting the branch line. The "H" poles are erected in line with the main conductors which are terminated on each leg with base connectors to the switches. With this arrangement it is possible to isolate any one section of the line while maintaining a supply to the branch lines.

The conductors forming the branch lines consist of either No. 8 S.W.G. "Copperweld" or 7/.093 sq. inch steel-cored aluminium, while at the terminal point of most branches a small outdoor pole-mounting transformer is mounted on a platform built on the pole, fig. 6, which transforms down from the 11,000-volt supply to feed into the 400-volt, 3-phase, 4-wire, low tension network. One of the branch lines—that feeding to Mansfield Road—terminates in a kiosk sub-station which is equipped with two oil circuit breakers and a small 11,000/400-volt transformer.

The 11,000-volt line ends at Rhodesia sub-station, fig. 7, at which point it is linked up with the existing 6,600-volt system of Worksop. This kiosk is almost as large as that at Manton and is equipped with 11,000-volt incoming and outgoing feeder control panels and three 6,600-volt feeder control panels in addition to the usual isolating links, current and potential transformers, ammeters, power factor indicators, wattmeters and the like. Space is also provided inside the kiosk for a small transformer and distribution board for supplying low tension current locally, while a large 1,000 kVA outdoor transformer is located close to the kiosk for interconnecting the 11,000-volt and 6,600-volt supplies.

It has already been mentioned that the main 11,000-volt line is looped into a kiosk sub-station at Sparken Hill. From this point a branch line is taken to a similar sub-station at Market Place, the low tension distribution network of which is interconnected with a third sub-station at Dock Road, figs. 8 and 9. This latter is fed at 6,600 volts direct

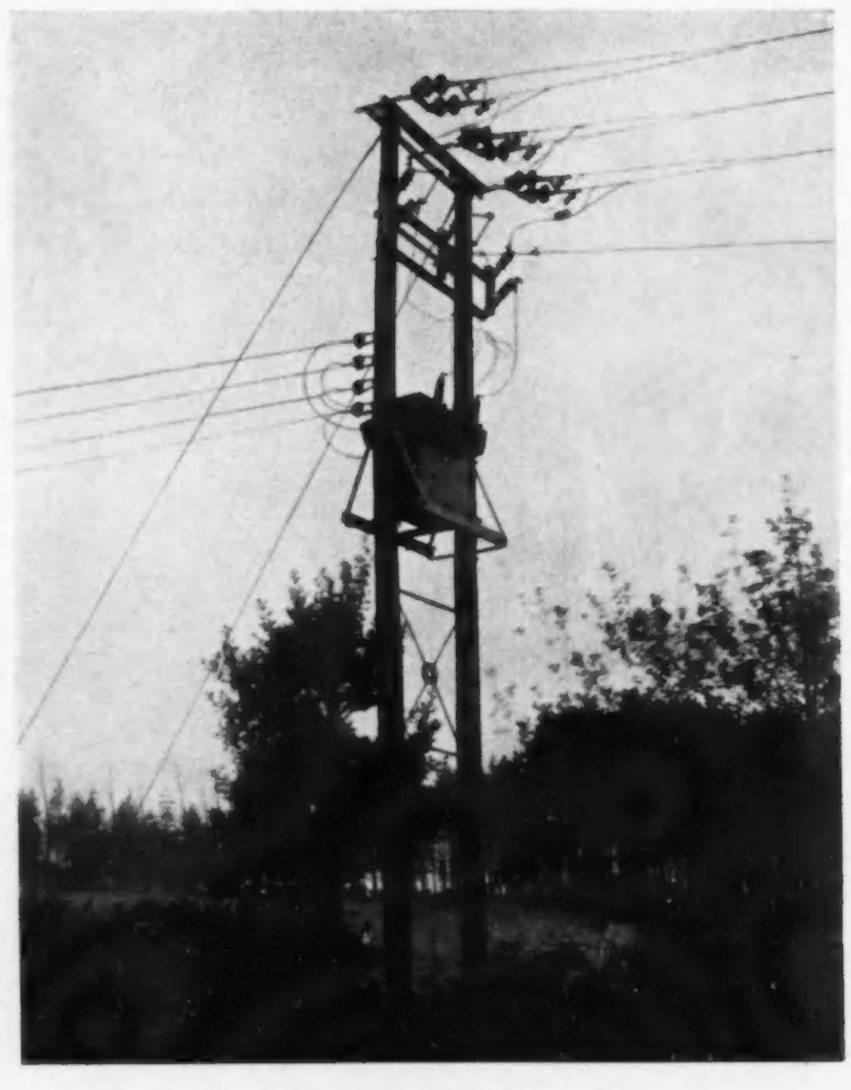

Fig. 6.—Terminal station with pole-mounted transformer.

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from the Electricity Works. These three sub-stations are of special design and are provided with transformers having on-load tap changing mechanism controlled from the Electricity Works by supervisory equipment. This system of supervisory control is a new development, capable of very wide application, and is undoubtedly the most interesting portion of the installation. It is therefore proposed to describe the equipment in detail.

SUPERVISORY CONTROL.

The method of remote supervisory control adopted, known as the G.E.C. Ten-point Tandem Supervisory Control System, provides a simple and inexpensive means of concentrating at a selected point the control of a large number of transformer kiosks of the type already described. It may also be used in connection with such plant as semi-automatic converting sub-stations, synchronous condenser equipments, mercury-arc rectifier stations, induction regulators, hydraulic and sewage pumping stations and hydro-electric equipment. While specifically designed to meet the requirements of the Worksop Corporation, the system is in certain respects similar to those supplied by the G.E.C. to the Central Electricity Board for serving the Central England area of the national "Grid."

As is indicated by the name of the system, the points to be controlled are connected in tandem. Only four pilot wires are required, such as two pairs of ordinary telephone lines, and these are looped into each point in any convenient manner and terminated at the central station. The economy and flexibility of the scheme is illustrated by the fact that when a new sub-station or kiosk is installed in a power distribution network already served by the system, it is necessary only to extend the pilots from the nearest existing point to provide full facilities for supervision and control of the added equipment.

Considerable economy is also effected in the design and amount of apparatus by limiting to ten the number of operations which can be carried out at any remote station, a number which suffices to meet the requirements of the average kiosk installation.

Fig. 8.—Dock Road sub-station showing arrangement of H.T., L.T. and transformer compartments.

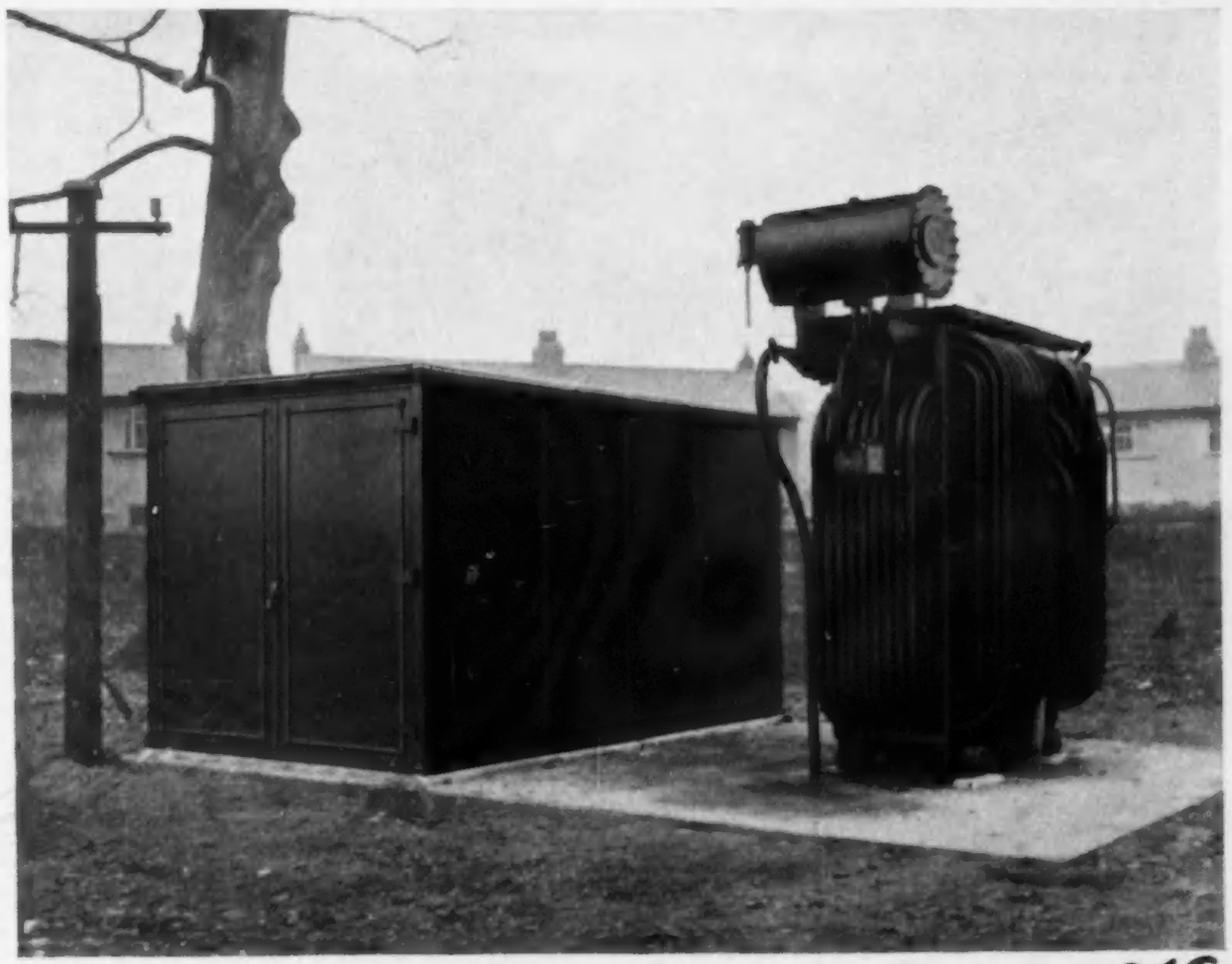


Fig. 7.—Rhodesia sub-station.

For example, provision for the following operations can be made at a central station controlling a network of transformer kiosks supplied by a ring main and equipped with on-load tap-changing gear :—

(1). Raising the transformer ratio.
(2). Lowering the transformer ratio.
(3). Indicating the transformer ratio.
(4). Indicating the local system voltage.
(5). Closing and indicating position of No. 1 circuit breaker.
(6). Tripping and indicating position of No. 1 circuit breaker.
(7). Closing and indicating position of No. 2 circuit breaker.
(8). Tripping and indicating position of No. 2 circuit breaker.
(9). Telephone call.
(10). Spare.

As applied to Worksop, the system has resulted in a capital saving of 75 per cent of the cost of

similar schemes hitherto available, and is so arranged that the following operations can be carried out from

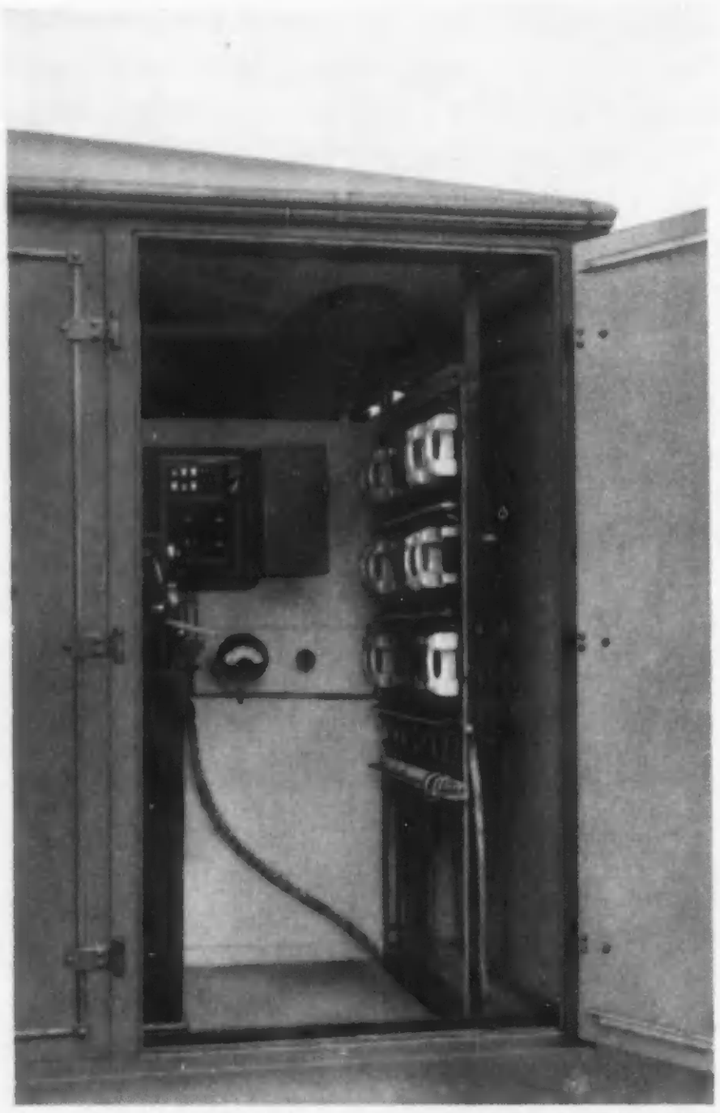


Fig. 9.—Interior of L.T. compartment at Dock Road sub-station, showing supervisory control apparatus.

the Electricity Works at the three kiosks now connected :—

(1). Raising the transformer ratio.
(2). Lowering the transformer ratio.
(3). Indicating the transformer ratio.
(4). Indicating the local system voltage.
(5). Tripping No. 1 circuit breaker.
(6). Indicating position of No. 1 circuit breaker.
(7). Telephone call.

The number of stations which can be worked in tandem on one pilot cable is theoretically almost unlimited, but practical considerations usually limit the total to ten.

The equipment at the Corporation's Electricity Works consists of :—

(*a*) Control panel or cabinet.
(*b*) Relay and selector equipment.
(*c*) 50-volt storage battery.
(*d*) Telephone instrument.

The control cabinet at the Electricity Works, illustrated in fig. 10, carries the meter for reading the system voltage at distant points, a dial of the automatic telephone type, two operating keys, and three strips of indication lamps. The associated relays and selectors are also mounted inside the cabinet. All apparatus possesses the same reliability as that required by public telephone systems and in this respect conforms to the relative specifications of the Post Office. Relays, for instance, carry duplicate platinum contacts.

The equipment at each of the kiosks consists of :

(*a*) Relay and selector equipment.
(*b*) Auxiliary contacts as required on the switchgear.
(*c*) A D.C. supply.
(*d*) Telephone instrument.

Fig. 10.—Remote supervisory control cabinet at the Corporation's Electricity Works.

Part of the apparatus at the Dock Road kiosk is shown in fig. 9 where the 24-volt D.C. supply is taken from the existing tripping battery.

The system is both simple and rapid in operation, and all indications are positive. To each sub-station a number is allotted, consisting of two digits, a further single digit number being given to each operation which has to be controlled. Selection of a sub-station is first obtained by operating a start key at the electricity works and dialling the appropriate number, whereupon a check-back lamp confirms the actual receipt at the selected kiosk of the dial impulses and the correct preparation of the selector equipment. At the same time all other stations are automatically locked out. A separate back-indication lamp is associated with each station thus ensuring positive indication of that selected, while providing also a definite warning to the operator in the event of incorrect selection due to faulty dialling or interruption of the pilot wires.

After selection of the station and receipt of the check-back signal, the dialling of the number corresponding to the desired operation completes the preparation of the sub-station equipment. A further check-back signal is now given at the control point, indicating by means of a lamp the particular operation for which final preparation has been made. The number dialled may, for example, be that allotted for indicating the position of the tap-changing switch, in which case a lamp individually associated with this operation will indicate the correct preparation to the operator. Separate lamps are again provided for operation check-back purposes thereby giving complete supervision of the actual number of all dial impulses received at the distant point.

After receipt of the correct "station" and "operation" check-back signals, the selected operation is performed by depressing a common key. In the example mentioned, this action controls the functioning of a contactor which causes a device connected to the tap-changing switch to send back a signal to the central station, where one of a strip of lamps is illuminated to indicate the actual point on which the tap-changing switch is resting. The whole system is finally brought to normal by restoration of the start key.

A similar procedure is followed for other operations, including the establishing of telephonic communication, when two of the pilot wires are used for speech transmission.

TAP-CHANGING SEQUENCE.

The transformers installed in two of the three kiosks feed into the 400 volt 4-wire distribution system, and in order to regulate and maintain the load taken by the transformers and to maintain the L.T. voltage constant for varying loads in the system, each transformer is fitted with an on-load tapping switch, fig. 12, controlled from the Electricity Works by the supervisory system described.

The tap-changing mechanism is driven by a small motor supplied with power from the 400-volt network. In order to enable a relatively small motor to be used and to ensure that the tap-changing operations are carried out completely and at the correct speed, the motor is arranged to store energy by raising a weight which, by falling to its original

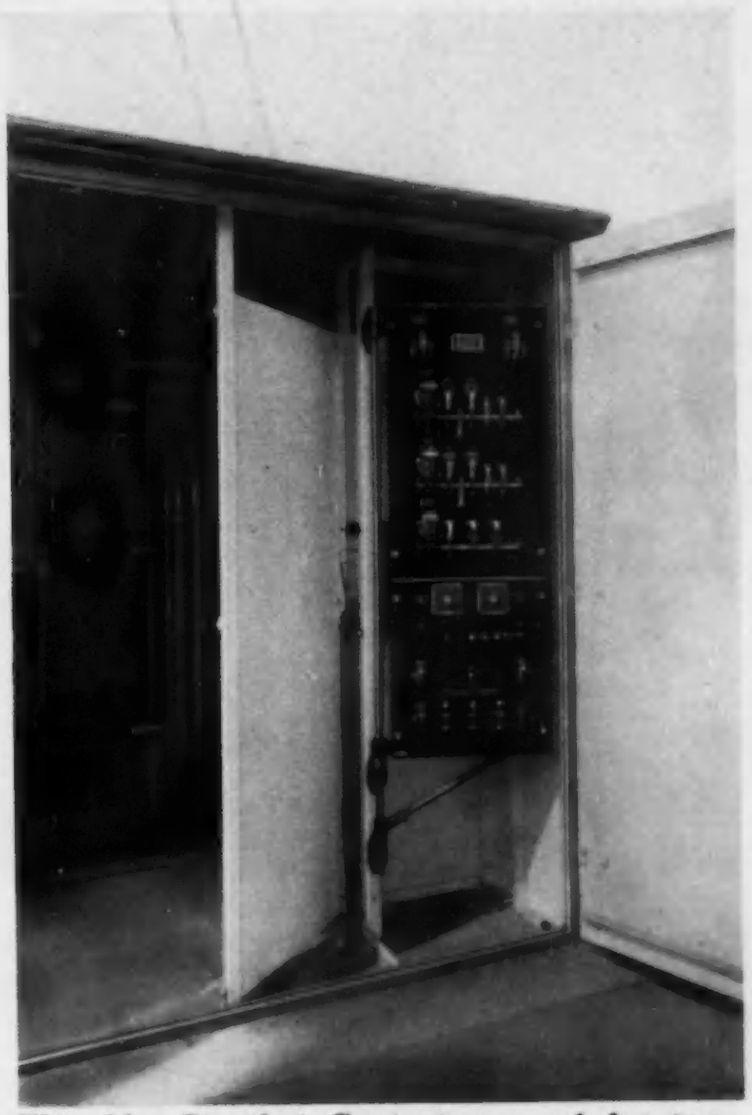


Fig. 11.—Starting Contactor panel for tap-changing motor at Dock Road sub-station.

position, actually carries out the tap-change. The weight can clearly be seen in fig. 12.

Should a tap-change on any transformer become necessary, the fact can be determined at the Electricity Works by the supervisory control equipment and the necessary steps taken to initiate the operation. This is effected by dialling the appropriate numbers and depressing a key at the control board at the Electricity Works, whereupon signals are sent to the selected kiosk where a power relay is operated which energises the starting contactor of the motor in the desired direction. The motor raises the weight through suitable gearing to the top of its stroke, at which point the weight falls free from the motor mechanism, and in its downward stroke engages with the tap-changing mechanism, carrying out the necessary change of ratio.

Further, when the weight reaches its top position a cam-operated switch opens and de-energises the motor starting contactor, which in turn de-energises the motor.

Arrangements are made so that the supervisory

gear can carry out only one change for each operation of the control key. If two changes are required in quick succession the gear must be operated twice.

In order to prevent the mechanism over running, when the limit of the tappings has been reached in either direction, limit switches are fitted which de-energise both the tap-changing contactor and the main motor circuit. These limit switches are driven directly from the selector switch mechanism and are therefore independent of any of the driving mechanism.

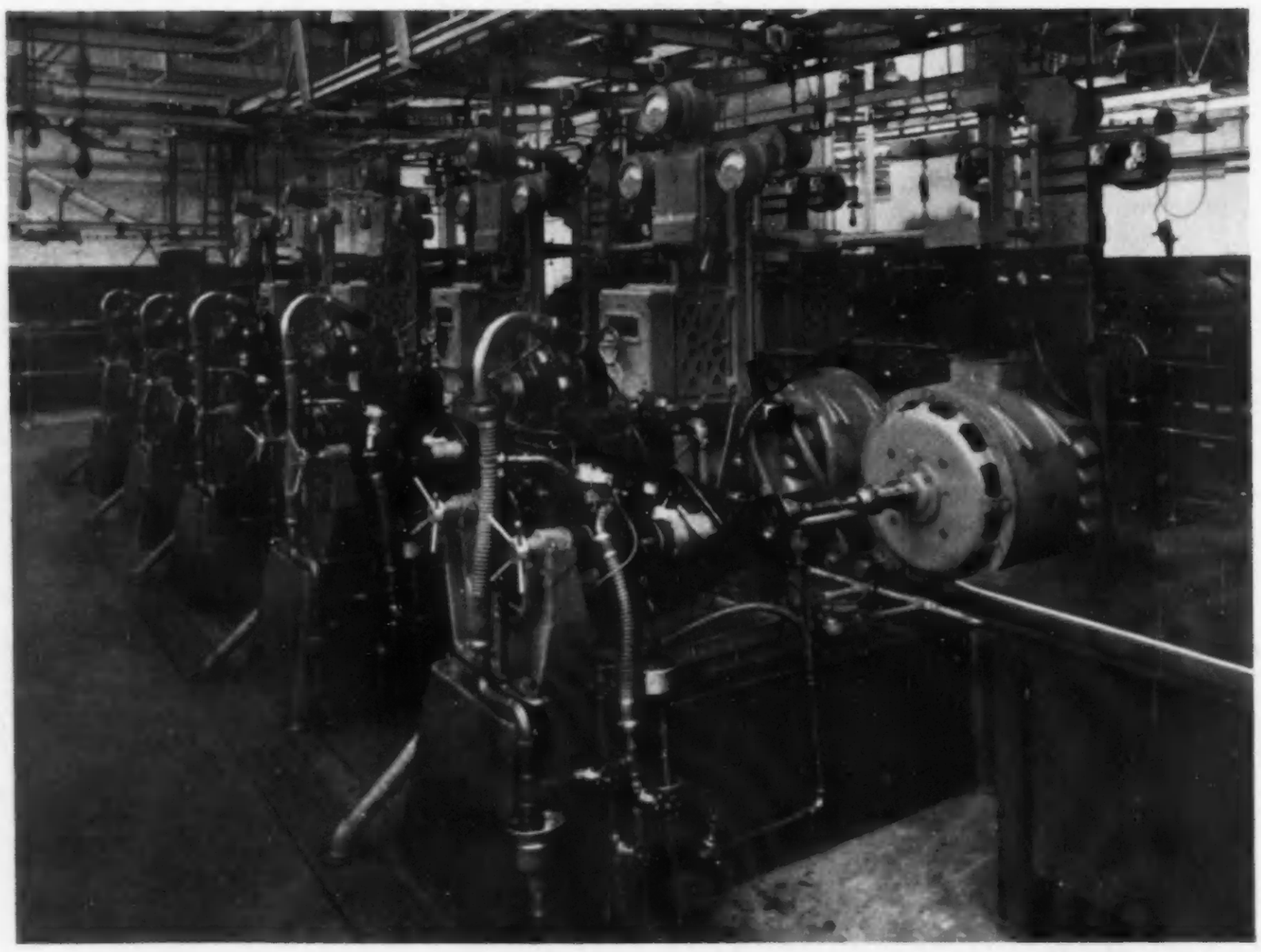
Fig. 12.—On-load tap-changing switch fitted to L.T. distribution transformer at Dock Road sub-station.

If it is desired to ascertain on which tapping any particular transformer is operating, a supervisory signal is sent out and an indication of the tapping is received. For this purpose each transformer is fitted with an auxiliary selector switch which makes a definite contact for each tapping position.

While the tap changing equipment is primarily arranged for remote supervisory control, by operating a switch on the panel in each kiosk the control for that particular transformer may be transferred from supervisory control to local push-button control, the push button being mounted on a panel in the kiosk, fig. 11. This form of operation is intended for testing purposes, but may, of course, be used for operating purposes in emergency.

In conclusion it should be mentioned that the overhead switchgear on the main 11,000-volt line, the kiosks, indoor and outdoor transformers and supervisory control equipment were manufactured and supplied by The General Electric Co., Ltd., to the specification of Mr. M. S. Mason, Borough Electrical Engineer of Worksop, while the overhead line itself was manufactured by Pirelli-General Cable Works, Ltd.

Automobile Engine Testing Equipment.



General view of the engine testing equipment at the Humber-Hillman motor car works, Coventry. Ten G.E.C. testing sets are installed, the engine being coupled in each case to a 20 kW D.C. motor which first drives the engine until the latter is "run in," and is then driven as a generator by the engine until a definite output is reached, the generators feeding back to line. Full protection is afforded by the control gear against overspeed, overload, no-load, etc.

The Service Performance of the "Monarch of Bermuda."

Since the Q.T.E.V. "Monarch of Bermuda" was placed on the New York–Bermuda run, her remarkable service performance has occasioned much favourable comment throughout shipping circles. The accompanying extract from the issue of "The Shipbuilder and Marine Engine-Builder," dated May, 1932, gives an interesting report of the winter sailings of the vessel from January to May of this year.

IN the January number of "The Shipbuilder and Marine Engine-Builder" was published a very full description with general-arrangement plans and drawings, of the Furness, Withy & Company's quadruple-screw turbo-electric luxury liner "Monarch of Bermuda," which was designed for the New York-Bermuda service and for pleasure cruising generally. This vessel, which has a gross tonnage of 22,424 and a shaft horse-power of 19,000, was built by Messrs. Vickers-Armstrongs, Ltd., at their Naval Yard, Walker, Newcastle-on-Tyne. The contract for the whole of the turbo plant, electric-propulsion and other electrical equipment was carried out by The General Electric Co., Ltd., while the designs to which the vessel was constructed were prepared by Messrs. William Esplen, Son and Swainston, Ltd., of London, and the building of both hull and propelling machinery was under their constant supervision and that of Mr. E. W. Harvey, the chief superintendent to the owners.

In the May number of the same journal appears the following note :—

"The "Monarch of Bermuda" left the Clyde on the 14th November, 1931, and proceeded slowly across the Atlantic with the definite object of arriving at New York on the 23rd. She left on her maiden voyage on the New York–Bermuda route on the 28th November and on that run she established a record for any vessel regularly employed in that service, the speed being 19.85 knots. She continued running in conjunction with the chartered vessel—the s.s. "Carinthia" of the Cunard Line—until the 2nd January, 1932, when that ship was taken off the charter, and the "Monarch of Bermuda" continued the service alone. A list of her sailings from the 2nd January to the 2nd May is given in Table I., and these have probably never been surpassed by an ocean-going vessel for regularity and precision.

"Up to the end of April the vessel maintained this schedule with strict punctuality, with the exception that on two occasions she sailed a few hours late owing to the extremely heavy weather experienced during practically the whole of the month of March. On one occasion in that month she was as much as 28 hours late on the run which ordinarily occupies practically 40 hours, the weather encountered being considered the heaviest ever known in this part of the world.

"It is interesting to note that in the four months January–April inclusive, the "Monarch of Bermuda" has been in port something like 52 times, 26 of which were in the difficult port of Hamilton, Bermuda, and she has travelled approximately 35,000 miles, the single trip being roughly 670 miles. Each time she is in port she ties up alongside the pier, and this, together with the necessary calls at the quarantine station at New York and at the pilot stations at the end of each trip (roughly 100 arrivals and departures in the four months), necessitates a great deal more manœuvring than the average liner is called upon to perform.

"It is obvious, therefore, that the ship herself, and particularly her turbo-electric machinery, have functioned with a very high degree of efficiency and reliability. Such a service performance must be extremely gratifying to all those responsible for the construction of the vessel and her machinery,

TABLE I.
"MONARCH OF BERMUDA" WINTER SAILINGS.

Leave New York.	Arrive Bermudas.	Leave Bermudas.	Arrive New York.
Sat., 2 Jan.	Mon., 4 Jan.	Mon., 4 Jan.	Wed., 6 Jan.
Thur., 7 Jan.	Sat., 9 Jan.	Sat., 9 Jan.	Mon., 11 Jan.
Tues., 12 Jan.	Thur., 14 Jan.	Thur., 14 Jan.	Sat., 16 Jan.
Sat., 16 Jan.	Mon., 18 Jan.	Tues., 19 Jan.	Thur., 21 Jan.
Thur., 21 Jan.	Sat., 23 Jan.	Sat., 23 Jan.	Mon., 25 Jan.
Tues., 26 Jan.	Thur., 28 Jan.	Thur., 28 Jan.	Sat., 30 Jan.
Sat., 30 Jan.	Mon., 1 Feb.	Mon., 1 Feb.	Wed., 3 Feb.
Thur., 4 Feb.	Sat., 6 Feb.	Sun., 7 Feb.	Tues., 9 Feb.
Tues., 9 Feb.	Thur., 11 Feb.	Thur., 11 Feb.	Sat., 13 Feb.
Sat., 13 Feb.	Mon., 15 Feb.	Mon., 15 Feb.	Wed., 17 Feb.
Thur., 18 Feb.	Sat., 20 Feb.	Sat., 20 Feb.	Mon., 22 Feb.
Tues., 23 Feb.	Thur., 25 Feb.	Thur., 25 Feb.	Sat., 27 Feb.
Sat., 27 Feb.	Mon., 29 Feb.	Mon., 29 Feb.	Wed., 2 Mar.
Thur., 3 Mar.	Sat., 5 Mar.	Sat., 5 Mar.	Mon., 7 Mar.
Tues., 8 Mar.	Thur., 10 Mar.	Thur., 10 Mar.	Sat., 12 Mar.
Sat., 12 Mar.	Mon., 14 Mar.	Mon., 14 Mar.	Wed., 16 Mar.
Thur., 17 Mar.	Sat., 19 Mar.	Sat., 19 Mar.	Mon., 21 Mar.
Tues., 22 Mar.	Thur., 24 Mar.	Thur., 24 Mar.	Sat., 26 Mar.
Sat., 26 Mar.	Mon., 28 Mar.	Mon., 28 Mar.	Wed., 30 Mar.
Wed., 30 Mar.	Fri., 1 Apr.	Fri., 1 Apr.	Sun., 3 Apr.
Tues., 5 Apr.	Thur., 7 Apr.	Thur., 7 Apr.	Sat., 9 Apr.
Sat., 9 Apr.	Mon., 11 Apr.	Mon., 11 Apr.	Wed., 13 Apr.
Thur., 14 Apr.	Sat., 16 Apr.	Sat., 16 Apr.	Mon., 18 Apr.
Tues., 19 Apr.	Thur., 21 Apr.	Thur., 21 Apr.	Sat., 23 Apr.
Sat., 23 Apr.	Mon., 25 Apr.	Mon., 25 Apr.	Wed., 27 Apr.
Thur., 28 Apr.	Sat., 30 Apr.	Sat., 30 Apr.	Mon., 2 May

and a great deal of credit is also due to Captain Jeffries-Davis and the ship's personnel for the carrying out of such an exacting programme.

"The sister ship—the "Queen of Bermuda"—is to be launched at Barrow-in-Furness in August."

Signal Current Protection of Feeders.

By W. WILSON, M.Sc., B.E., M.I.E.E.
Development Department, Witton Engineering Works of The General Electric Co., Ltd.

THE protection of overhead feeders differs from that of underground cables in that the provision of pilot wires, which are necessary for all true end-balance methods, is far more costly and troublesome with the former than with the latter. For steel tower lines, it is in general impracticable to support auxiliary conductors from the main pylons, and they have to take the form of a separate line, introducing a distinct source of expense and involving way-leave negotiations. Thus, although the use of pilot-wire schemes is the commonly accepted standard for underground transmissions, there is a general desire to escape from the expense of this dual provision with long overhead feeders, although many of them are so equipped at the present time.

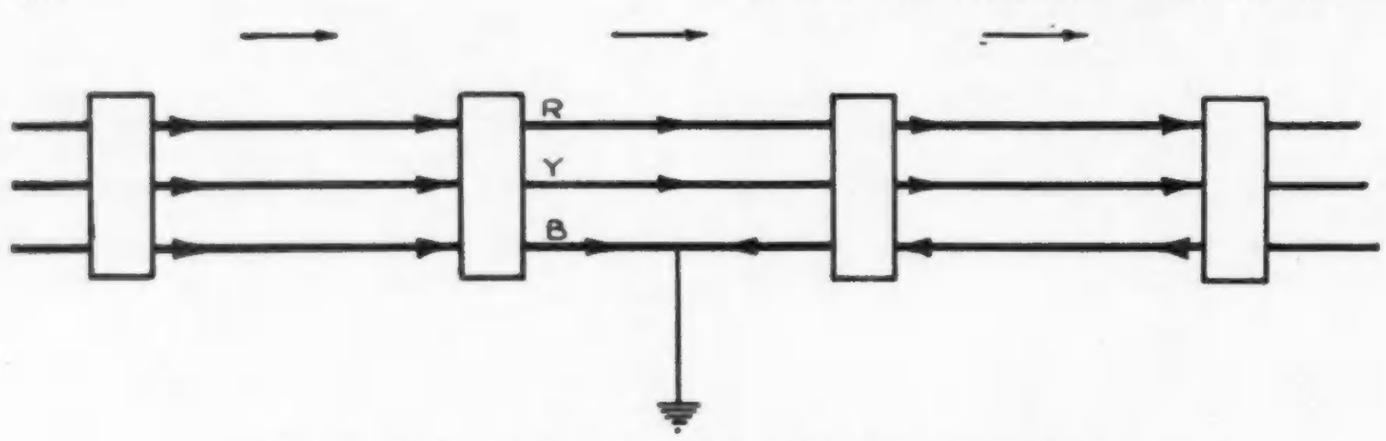


Fig. 1.—Effect of fault on flow of load in one phase.

A number of non-pilot methods have actually been employed for a considerable time. In the cases where feeders are run in duplicate, they may be protected by a parallel balance scheme; but naturally the opportunities to do this are limited. Balancing being thus impracticable in the majority of instances, recourse must be had to some type of discriminating overload method, preferably combined with phase-balance (or "leakage") protection for dealing with faults to earth only. For the less important lines, the discrimination may take the form of graded time-lags; but the high value of maximum delay involved where there are more than a small number of successive line-sections prevents this principle from being extended to main transmission lines. Instead, the "impedance" or "distance" method of time-discrimination is usually employed, in which the time-lag is limited to about a second, whatever the number of sections. Unfortunately, the relay system involved is complicated, and operation is not always very definite. This is especially the case for sections of less than about fifteen miles, for which it is usually considered that this method of protection cannot be recommended.

More recently, however, a type of scheme has been evolved occupying a mid-way position between the above two alternatives, in that while its sensitivity cannot be other than that of the overload, or overload-and-leakage type, it secures discrimination by means of an actual signal current passed from one end of the section to the other. In this way definite operation is secured without dependence upon time-lag and the relay arrangement is also simplified; but a channel must be provided for the signal current. In the two schemes to be described, this channel has been rendered comparatively inexpensive, since (1) it consists only of a single circuit, as compared with the three-phase circuit of the conventional pilot-wire scheme; (2) the magnitude of the current is more or less fixed and of a very small value; and (3) the communication channel is a single D.C. circuit in the first case, and a carrier-current circuit employing the main feeder in the second. Both of these schemes are therefore worthy of serious consideration when protection is required for an overhead feeder.

GENERAL PRINCIPLES.

In the usual type of end-balance pilot wire protection the magnitudes of the currents entering and leaving each phase of the feeder are directly compared, a fault being indicated by more current entering than leaving. For the signal current method, the presence of a fault is indicated by an overload entering and not emerging. By this method of detection, the necessity for a pilot current of the same kind as that in the feeder, and proportional

to the conditions in the latter, is obviated, the criteria being whether the signal is passing or not, and the position of overload and directional relays at the ends. For example, if directional relays at opposite ends of the same conductor both indicate a flow into the line, then there must obviously be a leakage path between the two, and a signal of constant strength that would pass only when this occurred could be made to afford the desired protection. There is some complication, however, owing to the necessity for protecting three separate conductors by means of the single circuit, as it would be uneconomical to triplicate the signalling arrangements; while in the case of dead-ended feeders there will not ordinarily be a reverse flow.

If the conditions in the three sections nearest a fault, as shown in fig. 1, be examined, it will be seen that the normal load, supposed to be flowing in the line from left to right, will continue in the two sound phases after the occurrence of the fault, which is located in the bottom phase of the middle section. The effect of such a fault would usually be to reverse the flow on the right, and to increase the flow from the left to overload proportions. Under certain conditions, the reversed flow would also constitute an overload, while in other circumstances there may be no actual reversal, the flow to the right of the fault merely being of less than overload value. The diagram, however, illustrates the more typical case occurring in a ring main or interconnector.

Now it is essential not only that the scheme shall trip out the faulty section, but also that it shall maintain closed all breakers on the adjacent sound sections. The relay system must therefore be so designed that it remains stable when power is passing into two phases of a sound feeder at one end and into the remaining phase at the other end. This requirement precludes the use of directional relays on each phase with their contacts connected in parallel, as they would give false operation in the section in question. To arrange the directional units for all the phases upon the one spindle would greatly increase the fault setting, and would be subject to considerable irregularity through the greater voltage drop at the end nearer the fault weakening the torque on the relay at this point. A polyphase relay is therefore scarcely admissible.

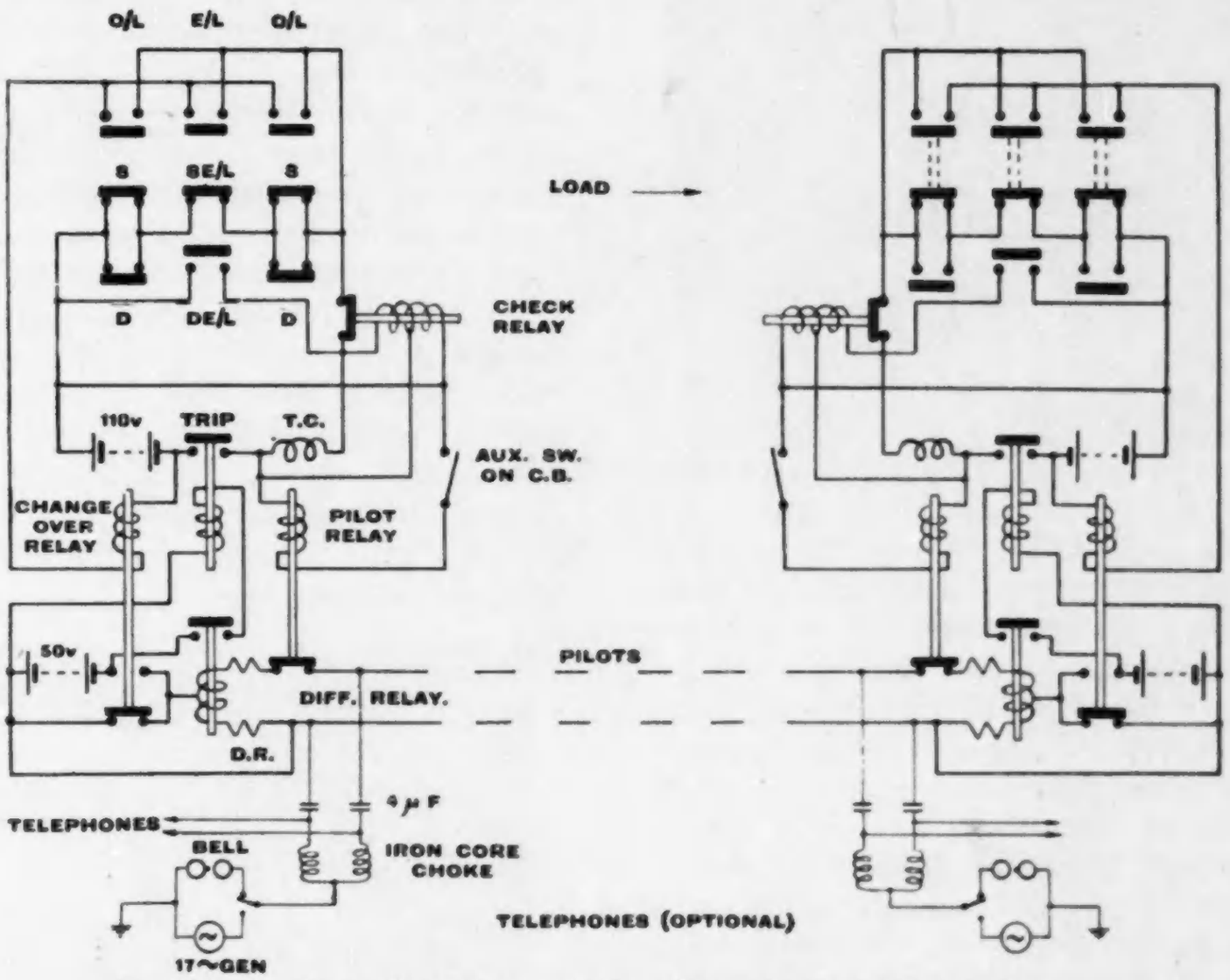


Fig. 2.—Kapp-Carrothers single pilot scheme of protection.

An arrangement of two over-current elements and one directional element in each phase has however been developed which has solved the problem, with the alternative that the two former may be combined into a single unit with double contacts if desired. As will be seen from the detailed description of the schemes, the effect is to produce tripping only if an overload passes into, and no overload passes out of any phase, a condition that forms a definite criterion of an internal fault. Further, by connecting the relays according to the directional overload-and-leakage scheme, instead of as three plain directional overload elements, greatly increased sensitivity may be given for faults to earth.

KAPP-CARROTHERS SINGLE-PILOT SCHEME.

First, the Kapp-Carrothers or "Duplex" scheme will be described, which uses either a single pilot wire and an earth return, or else two insulated pilots. The arrangement of nine over-current and directional relay elements, to which reference has just been made, occupies the upper portion of the diagram forming fig. 2, while a set of not more than five D.C. relays shown in the lower part of the illustration signals their relative positions from

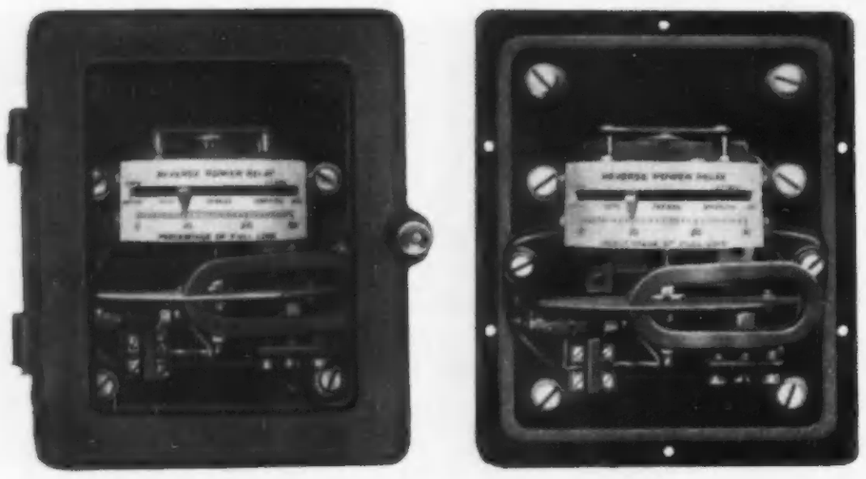


Fig. 3.—Views of "Salford" directional relay; the cover is removed in the right hand view.

one end to the other, and effects the appropriate tripping operations. It should be noted that this part of the scheme in fig. 2 has been designed to work with two G.P.O. telephone cores as pilots, having a total maximum resistance of about 1,500 ohms. It complies with the G.P.O. requirements as regards the pilot circuit being separate and highly insulated from the remainder of the secondary wiring (necessitating two more relays than would otherwise be fitted); also as regards the pilot current and potential being limited to 15 milliamperes and 50 volts respectively. An alternative method of providing a signal circuit can be obtained by employing an insulated strand in the earth cable of the transmission line.

The A.C. elements are energised by means of a three-phase potential transformer and three current transformers at each end. Only the relay contacts are shown, and it is understood that the vertical groups on the left and right are associated with the red and blue phases respectively, while the middle group are connected as for "leakage" protection, being only operated by an unbalanced flow to earth, or a "zero-phase-sequence" current. The top horizontal row represent over-current relay elements, called the "operating" units, the outer two having a setting of about 150 per cent of normal, and the middle one of about one-fifth this value. The bottom row consists of directional elements, the contacts of which, in the case of the two outer units, are normally closed, but are designed to open with great sensitivity when any power flows out of the feeder; while those of the middle unit are normally open, but close when any power flows into it. Finally, the middle horizontal row consists of three more over-current elements, called the "Stabilising" units, with normally closed contacts, which are opened by a current flow of 125 per cent of normal in the case of the outer two elements, and in the case of the middle element by a current of about one fifth this value. It is possible to combine the operating and stabilising elements by providing the one over-current unit with two sets of contacts, and this is indicated by broken lines in the right-hand part of the figure.

It will be seen that the combination of the two lower rows constitutes a very sensitive device which will maintain contact when the smallest flow passes into the line, but will open the circuit and so prevent operation when an over-current of 25 per cent above normal passes out of any phase, whatever the voltage, together with an "earth-leakage" arrangement which carries out an equivalent function for earth faults at a much lower fault setting. The use of the two sets of over-current elements (or alternatively of the one set with double contacts operating at the different settings) plays an important part in securing reliability and rendering the whole scheme independent of line voltage. For example, false operation cannot be caused by a sustained overload having a value approximating to the setting of the operating elements, which on account of a slight

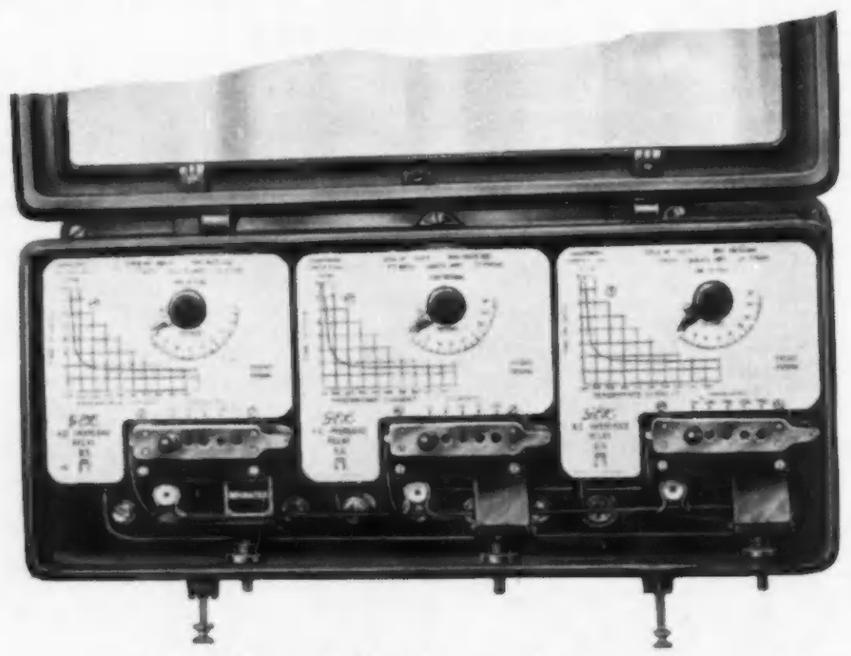


Fig. 4.—"Salford" overload relay.

inaccuracy in the setting of one element may be able to open the contacts at one end and close them at the other. Since operation at the incoming end is controlled by the operating element, and at the outgoing end by the stabilising element which has a definitely lower setting, there is a latitude of as much as 25 per cent in setting accuracy before false operation in the manner described can occur.

A further feature of this relay combination is that the directional leakage elements are able to close the circuit quite irrespective of the positions of any of the stabilising relays.

The signalling and tripping circuit, occupying the lower portion of the protection diagram, consists

of several D.C. relays, which together with the pilot wires (or wire and earth return) constitute a development of the "Duplex" circuit as used for telegraphy, and link up the contacts of the A.C. relays in the correct manner. Three D.C. units at each end are shown with insulated rods supporting the contacts. These are for the purpose of separating the upper part of the wiring (which has some connection with the A.C. power line) from the G.P.O. pilot circuit, by interposing a specified flashover distance of at least 15 kV. The D.C. relays are of the contactor pattern, and are therefore not only robust and reliable, but inexpensive.

There is only one feature in this part of the diagram which requires special note, namely, the differential relay, which though still of the contactor type, has its armature arranged horizontally and counterweighted to give great sensitivity. The coil is divided into two equal sections, which oppose each other when currents flow through them in opposite directions.

The sequence of operations may now be described. When a through fault occurs in one or more phases, both the stabilising and operating overload elements at each end move their contacts, while the directional relays close at the "home" and open at the "distant" end. At the home end (that from which the current is flowing) an "O/L" relay has closed while the

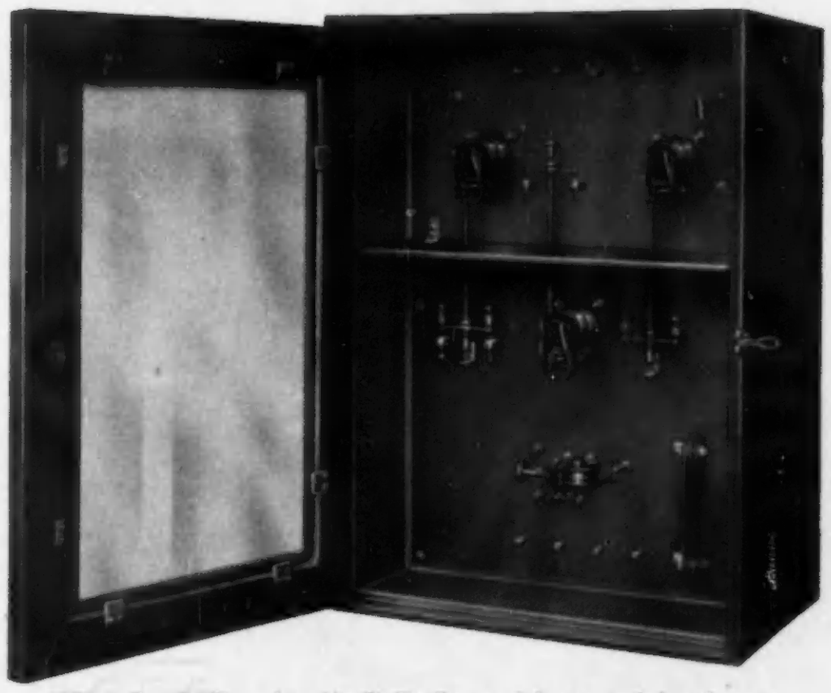


Fig. 5.—"Duplex" G.P.O. cabinet with three insulated rod relays.

"SE/L" and either the "S" or the "D" element of each paralleled pair are also closed. There is thus a complete circuit for the local 110-volt tripping battery and the coil of the changeover relay. The latter then lifts, connecting the insulated 50-volt battery to the pilot wires, from the mid-point of the differential relay to the far end of the duplicate resistance DR.

Two paths are available for the resultant current, of which the longer is through the upper half of the home differential coil, the pilot wires and the upper half of the differential coil at the distant end, the lower being short-circuited by the distant change-over relay. The shorter path is that through the lower half of the home differential coil and the resistance DR, which is so proportioned that the currents in the two circuits are equal, resulting in no movement of the home differential relay.

At the distant end, since at least one "S" and "D" pair will have both their contacts open, there will be no circuit for the tripping battery, and, as already stated, the change-over relay will not move its

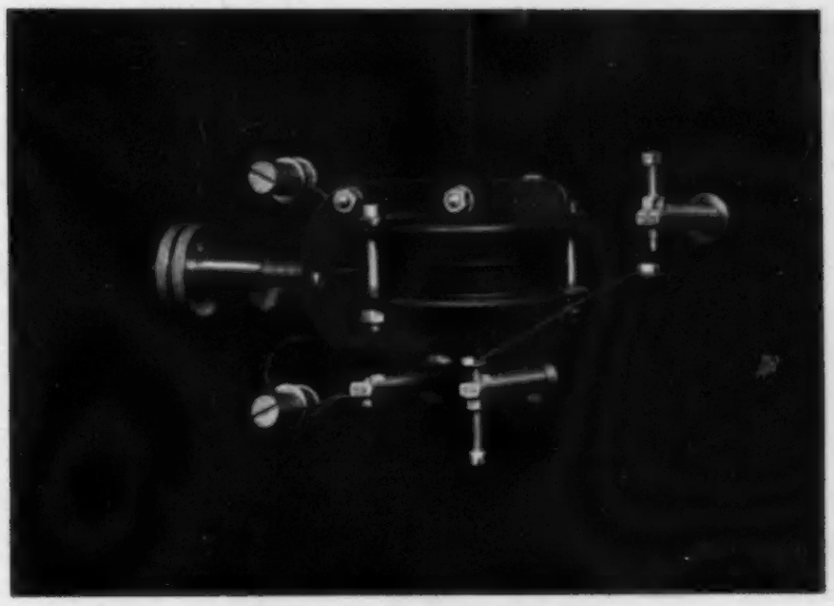


Fig. 6.—Differential relay.

contacts. The differential relay, having an unbalanced current in its coils, will operate, causing the tripping relay to function in its turn; but the circuit for the trip coil is incomplete owing to the opening of the stabilising contacts. There is thus no tripping at either end.

There is, however, a possibility, when the through fault ceases, that the distant stabilising contacts may reclose before the opening of the A.C. relays at the home end has enabled the change-over and other D.C. relays to open the distant tripping contacts. Since this would bring about false operation, the check relay has been added to open the tripping circuit whenever it is closed by the D.C. relays before the A.C. units have functioned. The check relay is an ordinary contactor type of unit with two opposing potential coils connected as shown. When the A.C. contacts have closed their circuit, the outer terminals of the check winding are connected together, and any current flows equally and in opposite directions through the two portions, causing the check contacts to remain closed. But when the impulse comes first from the D.C. relays, the left-hand portion is directly across the tripping battery, and the check relay at once opens the trip circuit.

If the fault current, instead of passing straight through the feeders, had flowed in from both ends, then each complete set of relays and trip gear would constitute a "home" end, and would function alike. The sequence described above would have proceeded as far as the operation of the change-over

relay, but since this would go on at each end, the two 50-volt batteries would be connected in opposition through the pilots, preventing any current from flowing in the lower half-coils of the differential relays. Both of these would then be operated by the current in the upper part of the windings, tripping both ends simultaneously.

The only remaining case to be considered is that of an internal fault which does not produce a reversed flow of overload proportions at the distant end, and so does not cause the stabilising elements to open their contacts. It does not matter then whether the directional contacts in parallel with them are open or closed, that is, the operation is not affected, whether the flow is into or out of the feeder, or even if it is zero. The closing of the trip relay while the stabilising contacts are closed will cause tripping at the distant end, but not initially at the home end. The auxiliary switch moving with the main circuit-breaker, however, will cause the pilot relay to open the pilot wire circuit, interrupting the current in the lower half of the home differential coil and bringing about tripping there also. When there is no necessity for the auxiliary switch to be isolated from the pilots, it may be arranged to open the latter direct without the interposition of the pilot relay; and when this is carried out, the separate "insulated" battery may also be eliminated.

It should be observed that a pilot wire which becomes broken accidentally, or disconnected, will cause tripping in the same way as described above for the first fault current that passes through the feeder, and thus "false security" cannot occur. The same result will follow if the pilot wire short-circuits at any point, as this event will unbalance the currents in the differential relay sufficiently to produce definite tripping.

The cases enumerated above include all types of fault with which the scheme may be called upon to deal, the special features accompanying earth faults being easily deduced from what has been said.

At the bottom of the diagram, the additional components that would be required for two-way telephony over the same pilot wires have been inserted. Standard telephone apparatus, including the usual 17-cycle ringing magnetos, are employed, and both protective gear and telephones function quite unaffected by each other when the former are connected in the manner shown. The leads from the pilots are taken through 4-microfarad condensers, at the further side of which the telephone is connected. A duplex iron core choke is interposed between this point and the ringing circuit, so arranged that the ringing current passes through the two windings in parallel, tending to produce opposing fluxes and so meeting with no reactance, while the current tending to short-circuit the telephone passes through the two in series and thus encounters a very high reactance.

The arrangement shown has given perfect results for pilots of the highest impedance so far employed, namely 960 ohms with standard attenu-

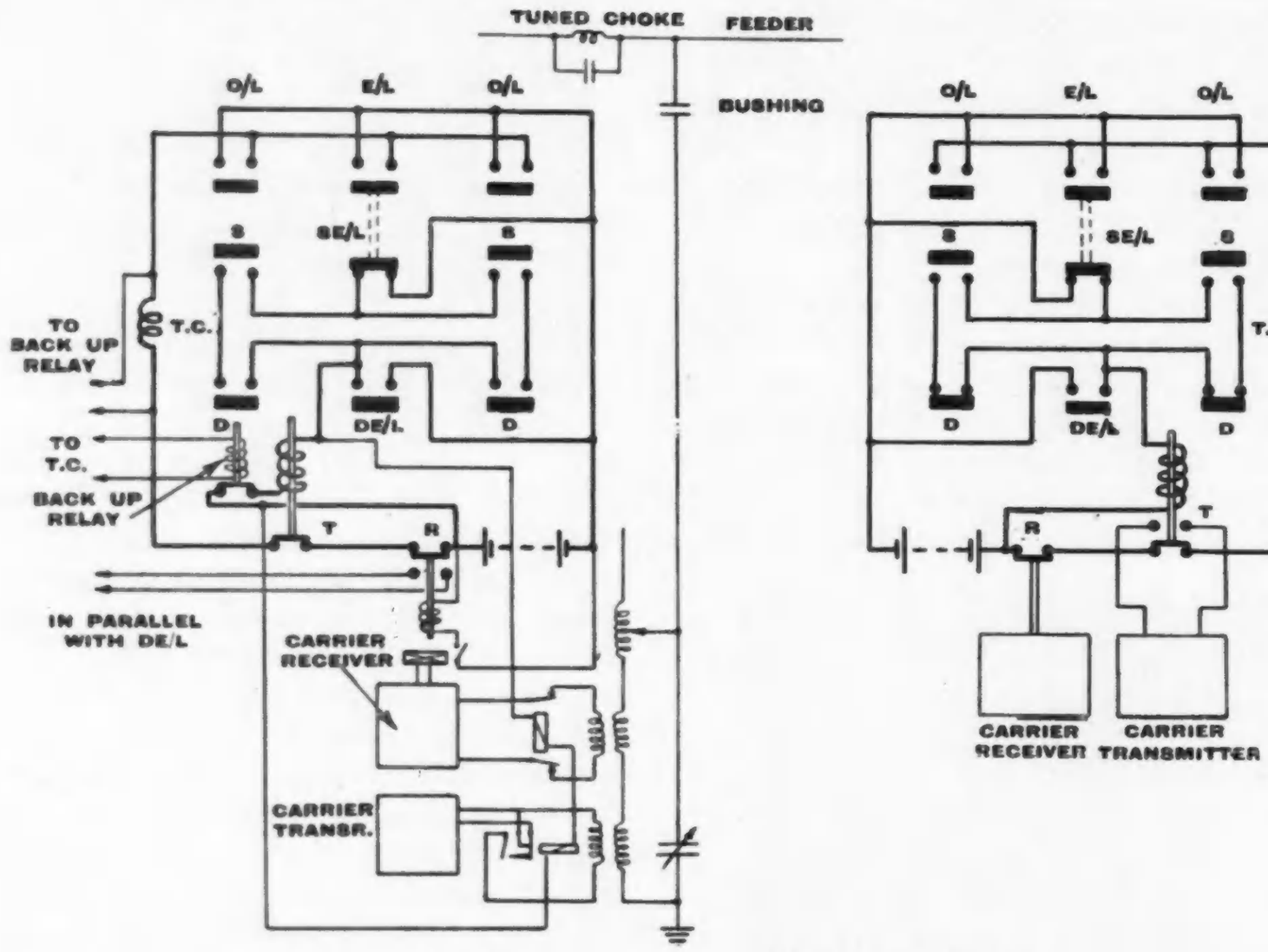


Fig. 7.—Carrier current system of feeder protection.

ation due to a distributed capacity of 0.6 microfarad, and will continue to do so for much higher impedances still. Although the use of the telephones has no effect whatever on the protective gear, and although the latter can be tripped by a heavy fault without producing the slightest sound in the receivers, the ringing generator at once causes tripping if a pilot wire is broken. The magneto thus affords a simple method of testing the pilot circuit whenever it is desired to do so.

CARRIER CURRENT SCHEME.

There are two sets of conditions under which the use of carrier currents is advantageous. First, they may be employed when it is desired to avoid a pilot-wire of any kind; and secondly, they may be used with a voice-frequency over telephone or other pilots of such length as to include repeater stations.

It is not a difficult matter to adapt the principle of the scheme previously described for carrier-current protection, and the diagram forming fig. 7 indicates how it is accomplished. In this, the left and right hand portions are again supposed to form the home and distant ends of a feeder section, the actual feeder again being omitted. For the sake of simplicity, the carrier current transmitting and receiving equipment is shown in full at the home end only, and is merely indicated on the right-hand part of the diagram. The latter is therefore the more convenient version as regards the general arrangement of A.C. and D.C. relays; and it is further simplified by the omission of the optional "back-up" devices which are also shown at the other end only.

The chief differences introduced by the use of the main line as a channel for "pilot" currents is that the scheme must be required to despatch a signal only when the feeder is sound; as breakdown would be liable to prevent operation if the system were arranged as with the Kapp-Carrothers scheme. Consequently, the signal is now sent from the distant end to prevent tripping when an excess current is passing out, instead of causing it when one is not emerging, at the same time as an abnormal current is flowing in at the home end. Thus the present scheme is in principle the converse of that previously described, and the relay arrangement is modified accordingly.

In order to enable the points of similarity and difference more clearly to be distinguished, fig. 7 has been arranged in the same general way as fig. 2, with the A.C. elements above, then the D.C. relays, and finally the high frequency portion below. The similarity between the two schemes is close as regards the O/L, S and D, elements, and also the earth leakage units, but since the S and D combination now has to *make* circuit when the feeder is sound, and must therefore only pass current when there is no overload and no reversal at the same time, the contacts are connected in series instead of parallel, and for all but the SE/L element are normally open.

Reference to the right hand end will show most clearly the simplicity of the D.C. units, which consist essentially of only two contactor type relays. In order to understand their operation it will be convenient to assume a through fault to have passed from left to right, closing one or more of the O relays at both ends and thus establishing a direct circuit through the battery and trip coil. At the same time the S and D elements at the right hand (distant) end will have closed the circuit for the coil of the transmitter relay (T), which not only opens the trip-coil circuit again but connects in the carrier transmitter. This sends a signal through one of the line conductors, which is picked up by the home-end receiver and operates the home relay R, opening the trip circuit at that end also. An internal fault in the feeder section would cancel the outgoing excess current, and the distant relays S and D would then not send the preventive signal. As before, an earth leakage passing into both ends brings about tripping whatever the amount of the leakage current.

During through faults, the scheme will seem to involve conflicting action between the O and D.C. relays, in that the one makes the trip circuit while the others break it. No difficulty is however caused thereby, since the D.C. relays are very quick acting and the application of the carrier current is instantaneous, rendering the stabilising process quite definite. The adjustment of the small time-lag of the "O" disc relays, by means of the arc of travel, is a simple matter if any additional delay is found advisable.

As with the overload elements of the previous diagram, it is permissible to combine the O/L and S members into one unit. It is simpler to do so with the earth leakage elements, since their movements are the converse of each other; but the others may also be combined if the design enables the successive closing of two contacts to be effected accurately at different settings.

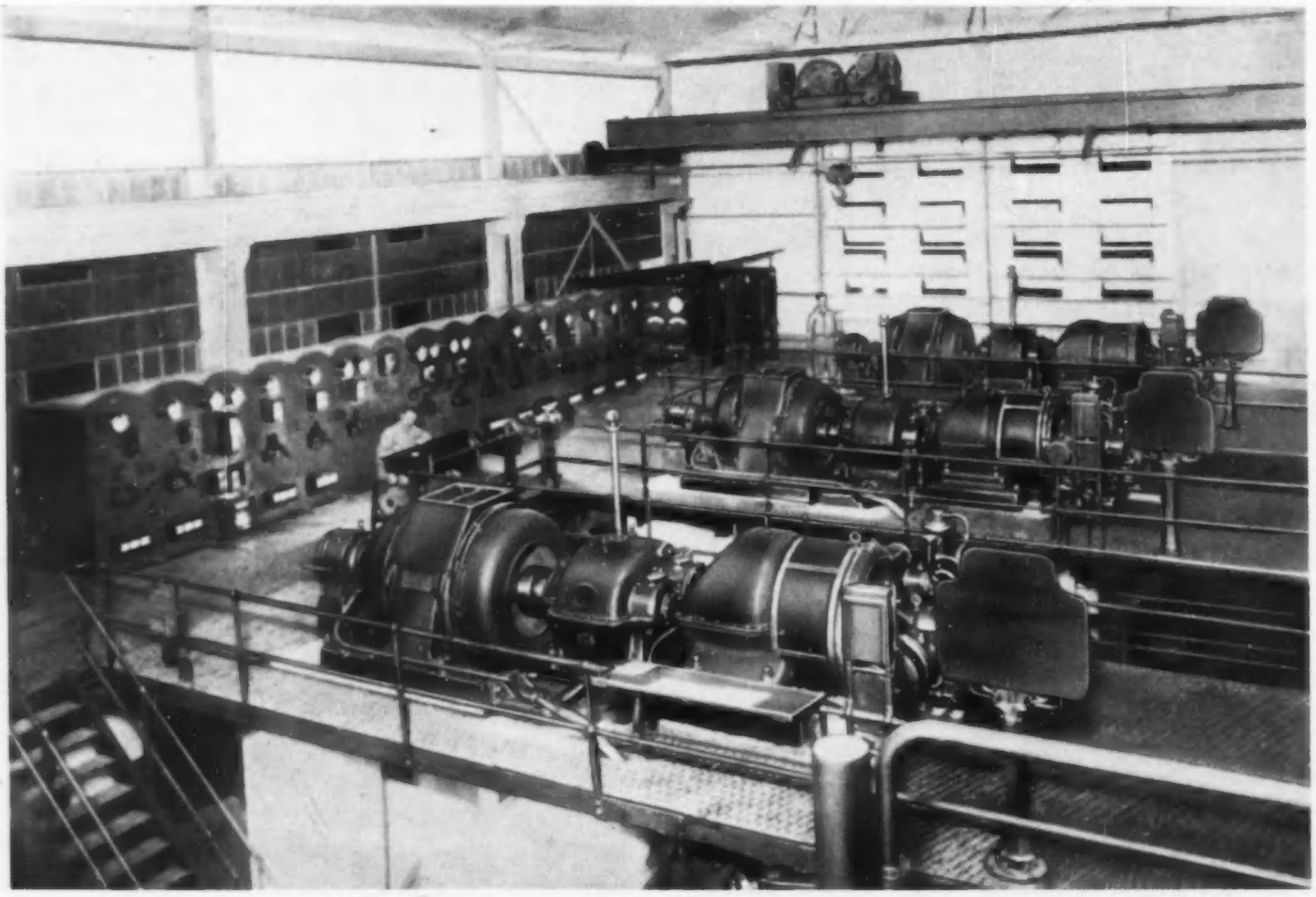
There is much less complication introduced by the carrier current part of the equipment than might have been expected. A single frequency is employed, generated by a valve which is kept continuously oscillating, but is not connected to the line until the transmitting relay functions. In the right hand part of fig. 7, this is shown with two sets of contacts, one opening the trip circuit and the other switching in the transmitter; while on the left the more complete version shows the more usual method, whereby separate relays are operated in parallel with the T relay. The lower of these removes a short-circuit across the high-frequency terminals of the transmitting valve, and connects it through a

transformer to a tuned circuit containing a variable condenser and reactance, while the other relay disengages the receiver. A condenser bushing couples the circuit to the line, and a tuned choke in the latter prevents the signals from passing beyond the section.

It is important to note that the valves in question are not of the ordinary "wireless" type, reliable though these are to-day; but are of the more robust form used for telephone repeaters, with a life of many thousand hours. The ageing of a valve can be estimated at any time by measuring the anode current, and it is good practice to fit a milliammeter which will give this indication upon the pressing of a button. An alarm system should also be provided which would ring a bell and operate an indicator if any derangement were to occur, such as the failure of a valve, interruption of the auxiliary power supply, or a fault in the high frequency apparatus generally. Practically all risk of failure is removed, however, if the valves are replaced while still in a comparatively new condition, such as after six months continuous running.

There are two optional extensions of the scheme indicated on the left-hand portion of the diagram, either of which will provide "back-up" features, in that the gear upon an adjacent section will be caused to function in the event of a failure in the section in question. The first of these consists of an additional relay connected in parallel with the trip-coil, which would open-circuit the T relay at the same end of the next section if the oil circuit-breaker refused to trip or to clear the fault, after a given small time-lag. The second takes the form of additional contacts on the receiver relay, the purpose of which is to short-circuit the directional earth leakage relay contacts on the adjacent protective equipment when through-fault conditions are registered. The stabilising signal will then be sent even if for some reason, such as the absence of the necessary excitation, the appropriate relay has not functioned.

Generating Plant at Demerara.



Three 1,500 kVA G.E.C.-Fraser and Chalmers geared turbo-alternators, 4,000 volts, 3 phase, 50 cycles, 6,000/1,500 r.p.m., installed in the Georgetown power station of the Demerara Electric Co., Ltd., British Guiana.

The Development of Commercial Photoelectric Photometers.

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Research Laboratories of The General Electric Co., Ltd., Wembley, England,

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Osram G.E.C. Lamp works.

The development of the photoelectric cell has made possible the construction of photoelectric photometers which allow of an accuracy being attained in everyday commercial practice comparable with that of the best visual standard photometry. This article deals with the design of such photometers for various purposes and for lamps of all types ranging from those used for everyday lighting service to lighthouse lamps of powers up to 10 kW.

IN photometric measurement, the average human eye is the indicator by means of which comparisons are made and standards fixed. Now there are very large variations of sensitivity among human eyes, and, in practice, the effect of an average eye has to be simulated by co-ordinating the readings of large numbers of trained observers. This method is, in fact, the one still relied on for the calibration of the light standards maintained by the various national testing laboratories and the first sub-standards which depend on them. In the case of photometry of a less exact kind, such as that used in the control of electric lamp manufacture and the maintenance of commercial lamp specifications, considerations of time and expense make it impossible to use anything like the same number of observers or of readings. As a result, the accuracy of commercial photometry, dependent on the minimum number of visual readings, was until quite recently of such a low order that it seriously limited the increase of precision in lamp manufacture.

Latterly, however, the development of the photoelectric cell has made possible the construction of photometers for commercial work in which the human eye is replaced by an electric one, and if cells of suitable type are chosen they will reproduce with extraordinary accuracy and ease the behaviour of that hypothetical average human eye which has hitherto been so costly and difficult to provide. As a result, commercial photometry can now be carried out by a single relatively unskilled observer to an order of accuracy comparable with that attained by the trained teams used in standard visual photometry, and at a speed as great as, or greater than, that with which commercial photometry can be carried out visually.

In what follows, the design of practical photoelectric photometers of various types is discussed in detail, and at the end of this description are given some data illustrating numerically what has just been stated on the relative efficiencies of visual and photoelectric methods.

THE PHOTOELECTRIC CELL AND THE AMPLIFIER.

The principal requirements of a photoelectric cell for use in photometry are that the relation between the light and the photoelectric current shall remain constant for long periods of time and give the same response to light varying in colour over the range covered by general service lamps, which correspond with Tungsten operating at colour temperatures from 2300°K to about 2800°K. If the cell itself does not respond equally to equal amounts of light of different colours it is desirable that it should be readily corrected by the use of a coloured screen of a fairly high transmission. It is also very desirable, especially for work of high precision, that the photoelectric current be strictly proportional to the luminous flux received by the photoelectric cell.

The K.M.V.6 photo cell which was developed in the Wembley Research Laboratories of the G.E.C. and is commercially available has such characteristics and is therefore eminently suitable for photometric purposes.

A satisfactory cell being available, it was necessary to devise some form of amplifier capable of magnifying the response of the cell by a certain factor and remaining constant in ordinary use, or alternatively, a null method in which the amplifier in effect functions as a highly sensitive galvanometer to indicate a balanced condition. In practice the former method can only be applied where measurements are made to a commercial accuracy and is

unsatisfactory for precision measurements. When the second method is adopted a valve bridge amplifier is used as shown in fig. 1. In this arrangement the bridge is first balanced with no light on the photo-electric cell. When light is allowed to fall on the photo-cell the voltage across the grid leak unbalances

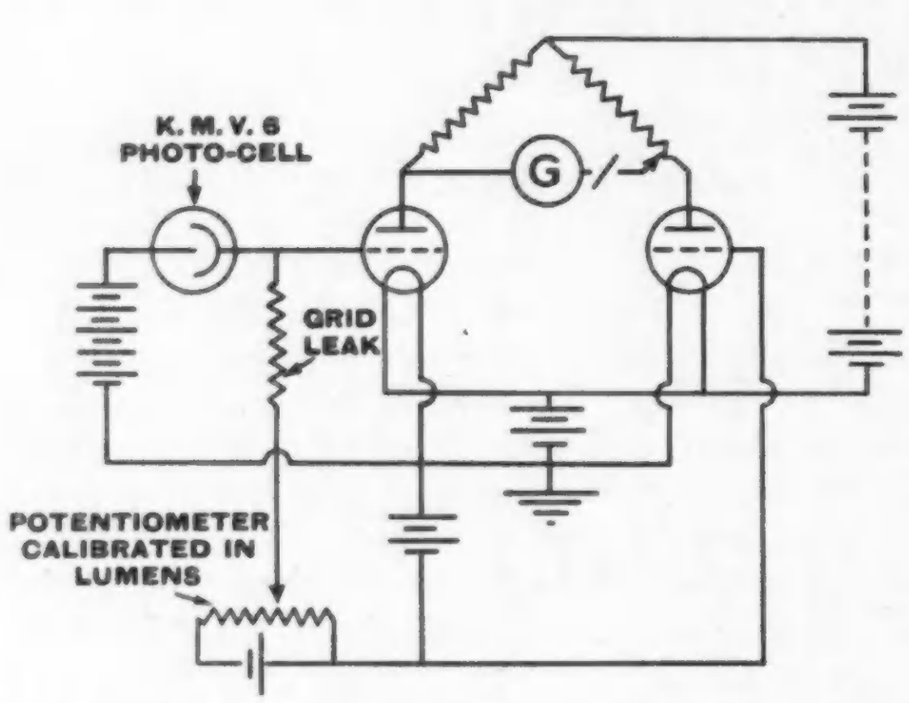

Fig. 1.—Circuit diagram of photometer for measuring lumens.

the bridge as indicated by the galvanometer deflection which can be restored to zero by applying an opposing potential from a potentiometer. When the galvanometer is balanced the voltage applied by the potentiometer will be directly proportional to the photoelectric current. If a cell is used which has a linear relation between photoelectric current and luminous flux, then the potentiometer can be calibrated to read directly in lumens.

It was found that the two principal difficulties to be overcome in the design of these amplifiers were to retain sufficiently high and constant insulation in the grid circuit, and to screen the apparatus from external electrostatic and electromagnetic disturbances which otherwise would tend to make the amplifier unstable.

In order to obtain the requisite amplification when measuring very low values of light flux (without additional stages of D.C. amplification), high grid leak values must be used. Owing to surface leakage troubles it is extremely difficult to maintain constant such high resistances and it has been found necessary to take very special precautions. In the latest form of amplifier the photoelectric cell, grid leaks and amplifying valves *are sealed into an evacuated vessel. This gives great freedom from those day to day changes, or variations during the day, which previously occurred on account of surface leakage and temperature effects.

*—The valves used are electrometer triodes of very special construction having a very high grid insulation and requiring an anode voltage of only 6 to 10 volts.

DESIGN OF PRACTICAL PHOTOMETERS.

It is now proposed briefly to describe the design of various photoelectric photometers suitable for making commercial and precision measurements employing as a light measuring unit the photoelectric cell and amplifier arrangements.

(*a*) *Direct-reading Lumen Photometer.*

The first photoelectric photometer[1] made on these lines was designed for measuring the lumen output of general service lamps from 15 to 150 watts, vacuum and gasfilled. This photometer (fig. 2) consisted essentially of a cubical photometric integrator of 2ft. 6in. side, having a small aperture about 2 inches square in one side suitably screened from the direct light from the lamp under test. Through this aperture luminous flux is received into an adjoining small subsidiary integrator containing the photoelectric cell. If the main integrator is suitably designed, the luminous flux in the subsidiary integrator is directly proportional to the total lumens of the lamp in the main integrator. Consequently the photoelectric cell with suitable amplifying arrangements previously mentioned can be used to obtain measurement of total

1. G. T. Winch J.I.E.E., May, 1930, Vol. 68, p. 533.

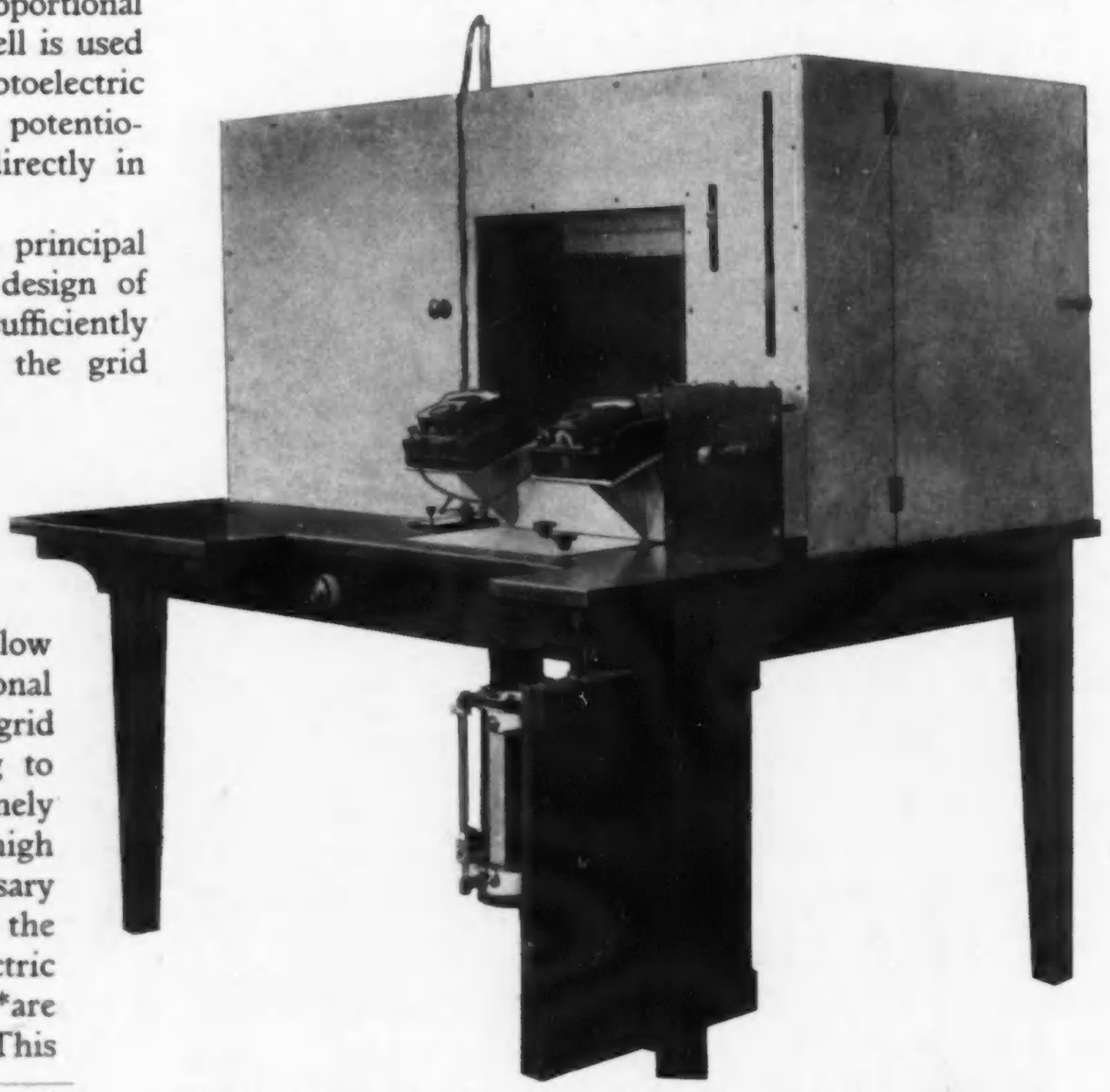

Fig. 2.—Photometer for measuring lumens of 15 to 100 watt vacuum and gasfilled lamps.

lumens. In order to correct for the small differences between the colour sensitivity of the photoelectric cell and that of the "average eye," a colour filter is so arranged as to be adjustable across the aperture between the two integrators. A shutter working in a direction at right angles to that of the colour filter enables the total amount of light entering the subsidiary integrator to be accurately adjusted while leaving constant the ratio of filtered to unfiltered light. By the use of standard lamps the apparatus can be calibrated so that the scale reads directly in lumens.

(*b*) *Direct-reading Lumen-per-watt Photometer.*

Another very similar instrument is that shown in fig. 3. This serves a dual purpose, since not only can the total lumen value of the lamp be measured in the manner already described, but by the following method, lamps of various wattages can be measured on a direct reading lumen-per-watt scale. A smaller instrument of this type for measuring lumens-per-watt only is in use at the Osram-G.E.C. Lamp Works.

In a modern lamp factory where a limited number of type sizes are manufactured under closely controlled conditions, the spread in lumens and watts of individual lamps will be comparatively small. It is nevertheless desirable to determine the magnitude of the spread in the efficiency at rated volts for sample lamps so that the necessary control of the manufacturing processes can be maintained.

For small changes of lumens and watts from some nominal value, as in the case cited above, an approximation to the value of $\frac{\text{lumens}}{\text{watts}}$ can be obtained by the following "subtraction" method.

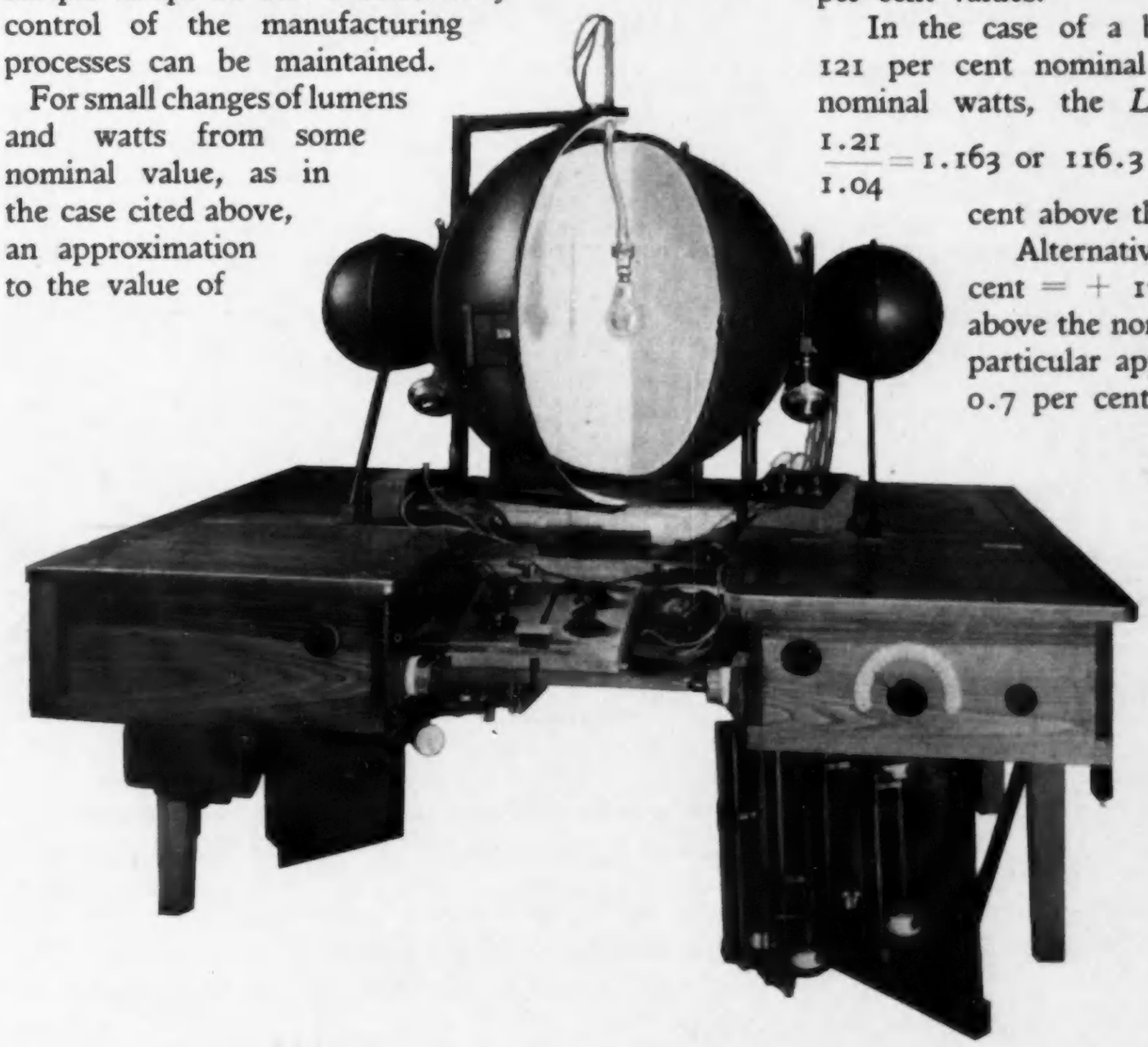

Fig. 3.—Apparatus for measuring lumens and lumens-per-watt.

Considering a perfectly rated lamp with reference to badly rated lamps of the same nominal rating the lumens, the watts and lumens-per-watt of the perfectly rated lamp can be assumed to be 100 per cent values.

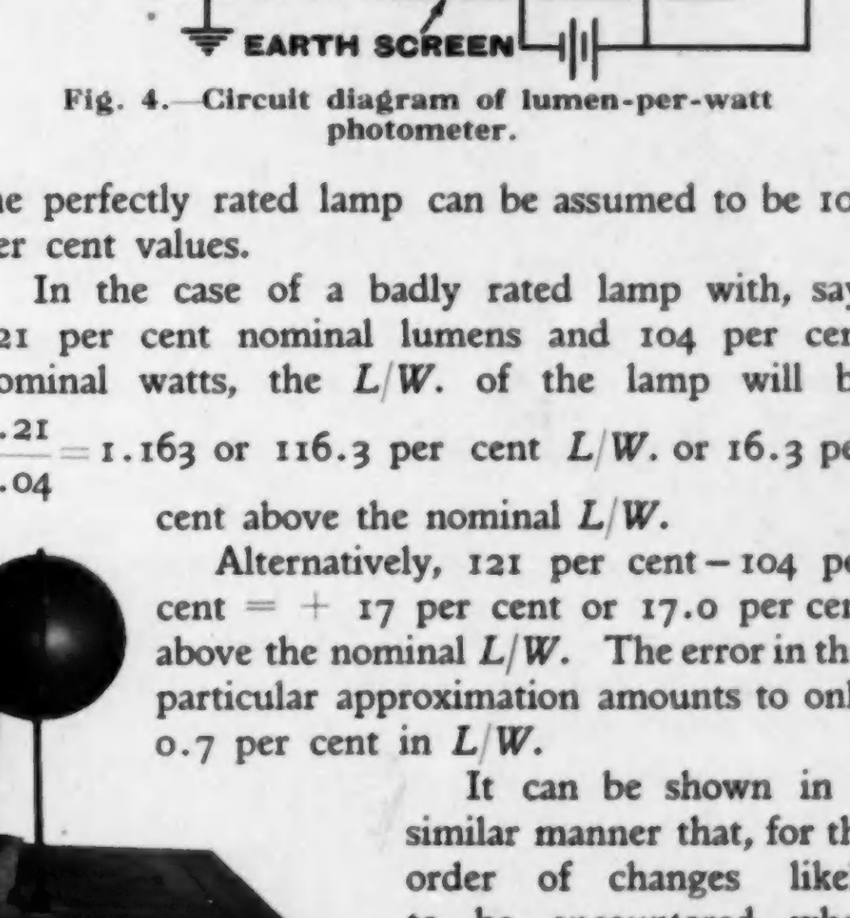

Fig. 4.—Circuit diagram of lumen-per-watt photometer.

In the case of a badly rated lamp with, say, 121 per cent nominal lumens and 104 per cent nominal watts, the L/W. of the lamp will be $\frac{1.21}{1.04} = 1.163$ or 116.3 per cent L/W. or 16.3 per cent above the nominal L/W.

Alternatively, 121 per cent − 104 per cent = + 17 per cent or 17.0 per cent above the nominal L/W. The error in this particular approximation amounts to only 0.7 per cent in L/W.

It can be shown in a similar manner that, for the order of changes likely to be encountered when measuring lamps of any particular nominal rating, the errors due to this approximation are usually within ± 1 per cent in the lumen-per-watt determination.

This principle has been utilized in the design of a photoelectric rating photometer[2] and the circuit shown in fig. 4 adopted. The lamps to be tested

2. British Patent No. 356,944.

are operated in a photometric integrator and the photo-cell receives luminous flux in proportion to the lamp lumens as in the first photometer (fig. 1). The amplified photoelectric current produces a potential between *A* and *B* (fig. 4) which varies directly with the lamp lumens. The potential across a suitable resistance *R* in series with the test lamp will vary directly with the amperes through the lamp. So that, for all lamps set up at one voltage, the potential across *R* will vary directly with the watts. By arranging the potential across *A B* to be equal to that across *R* for a lamp of correct rating, and by arranging the circuit so that these two potentials are in opposition with a galvanometer *G* to measure the difference, then the deflection, if any, will be proportional to lumens-per-watt (within the accuracy of the above approximation). The galvanometer scale can therefore be calibrated directly in lumens-per-watt. By means of stud switches, the tappings on the resistance *R* in series with the lamp can be changed for the particular voltage and wattage lamp being measured, so that the voltage across *R* will be the same for a lamp of any rating if it consumes exactly nominal watts.

(*c*) *Apparatus for Measuring Colour Temperature and Lumens*[3].

The apparatus illustrated in fig. 5 can be used to measure the colour temperature at which incandescent lamp filaments are operated. It utilizes the principle that the temperature can be measured by the ratio of the radiation at two different wavelengths[4]. As the temperature of a body rises it radiates a higher proportion of blue light; hence if two cells are used, one more sensitive to blue light than the other, and both receive integrated light from the same source, then the ratio of the photoelectric currents should be related to the colour temperature of the source.

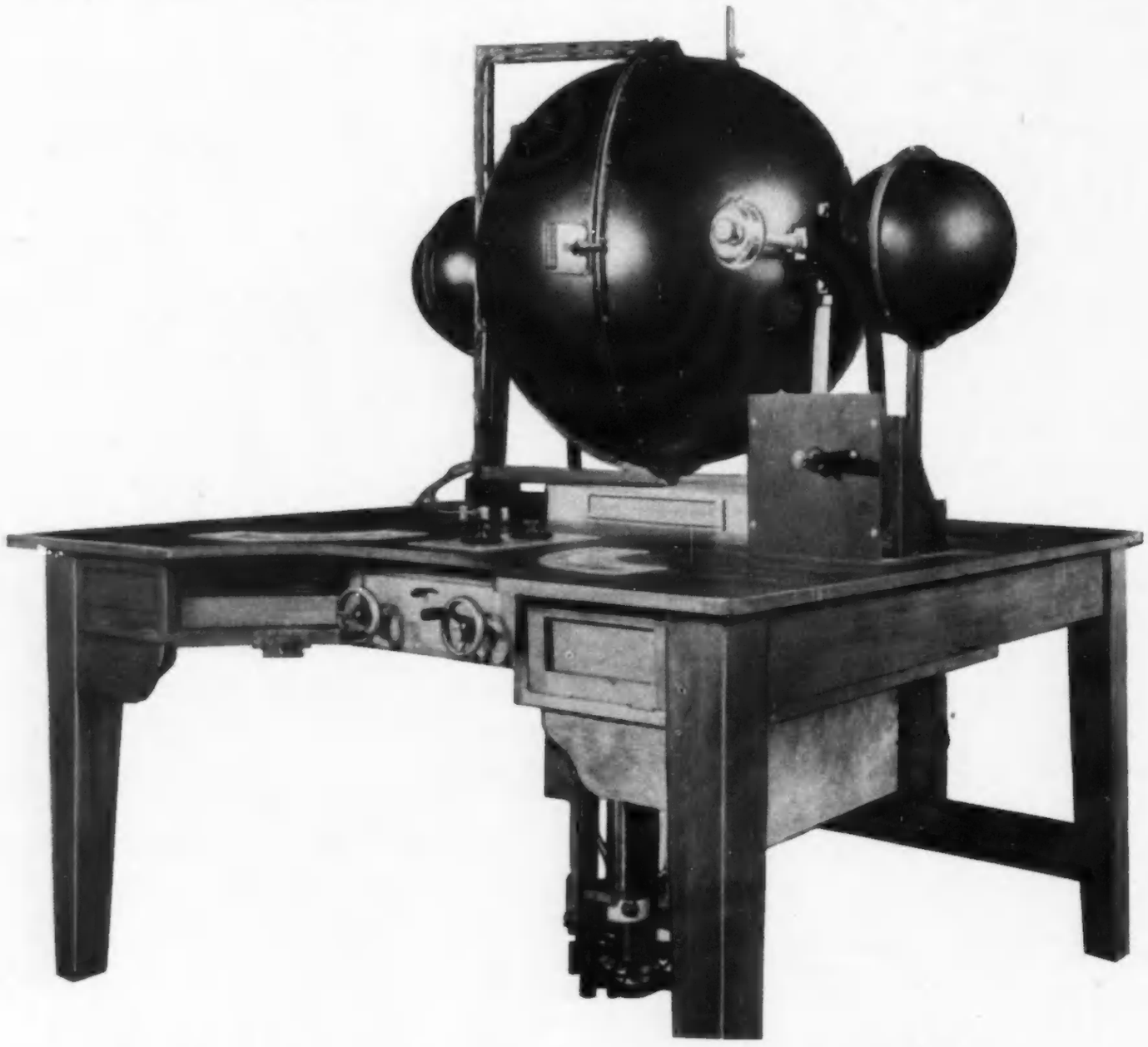

Fig. 5.—Apparatus for measuring colour temperature and lumens.

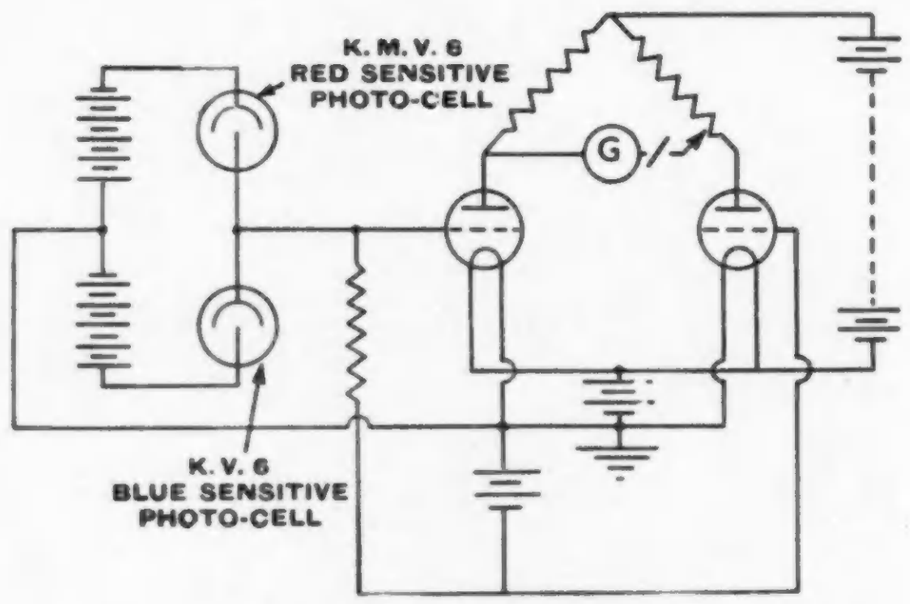

Fig. 6.—Circuit diagram of colour temperature apparatus.

3. G. T. Winch, Jour. Sci. Insts., December 1929. Vol. 6, p. 374.

4. N. R. Campbell, Jour. Sci. Insts, March 1925, Vol. II. p. 177.

In practice two photo-cells are used having maximum sensitivities at wavelengths of approximately 0.45 and 0.6 μ respectively. These cells are mounted in two subsidiary integrators, both of which receive integrated light from the main integrator in which the lamp under test is operated, the amount of light entering each subsidiary integrator being controlled by shutters. It has been found that, instead of measuring the ratio of the photoelectric currents, it is more convenient to arrange the cells in a bridge as shown in fig. 6 so that the photoelectric currents are in opposition and any difference throws the valve bridge amplifier out of balance. The shutter is then adjusted over one cell until the two photoelectric currents from the two cells are equal. The shutter scale can then be calibrated in colour temperature. It is interesting to note that when using a K.M.V. 6 (red sensitive) and a K.V.6 (blue sensitive) cell in this apparatus a linear relationship was found to exist within the expected accuracy of measurement from 2000°K to 3600°K (approximately melting point tungsten).

This photometer can also be used for measuring lumens by throwing over a switch which connects the two photo-cells in parallel. A potentiometer is then used to determine the lumens as in the first photometer, fig. 2.

THE PHOTOMETRY OF LARGE LAMPS.

The various photometers just described have been designed in the first place for measurements on lamps of the type used in ordinary lighting service. With the increasing use of lamps of very large wattages for lighthouses, aerodromes and similar purposes, it has become necessary to provide photometers capable of measuring their performance. While these employ the principles already described, the size of these lamps and the power they require give rise to electrical engineering problems of quite a special nature. These are of such interest that it is proposed here to describe in some detail a photometer designed in conjunction with the Osram-G.E.C. Lamp Works for the measurement of lamps rated as high as 10 kW.

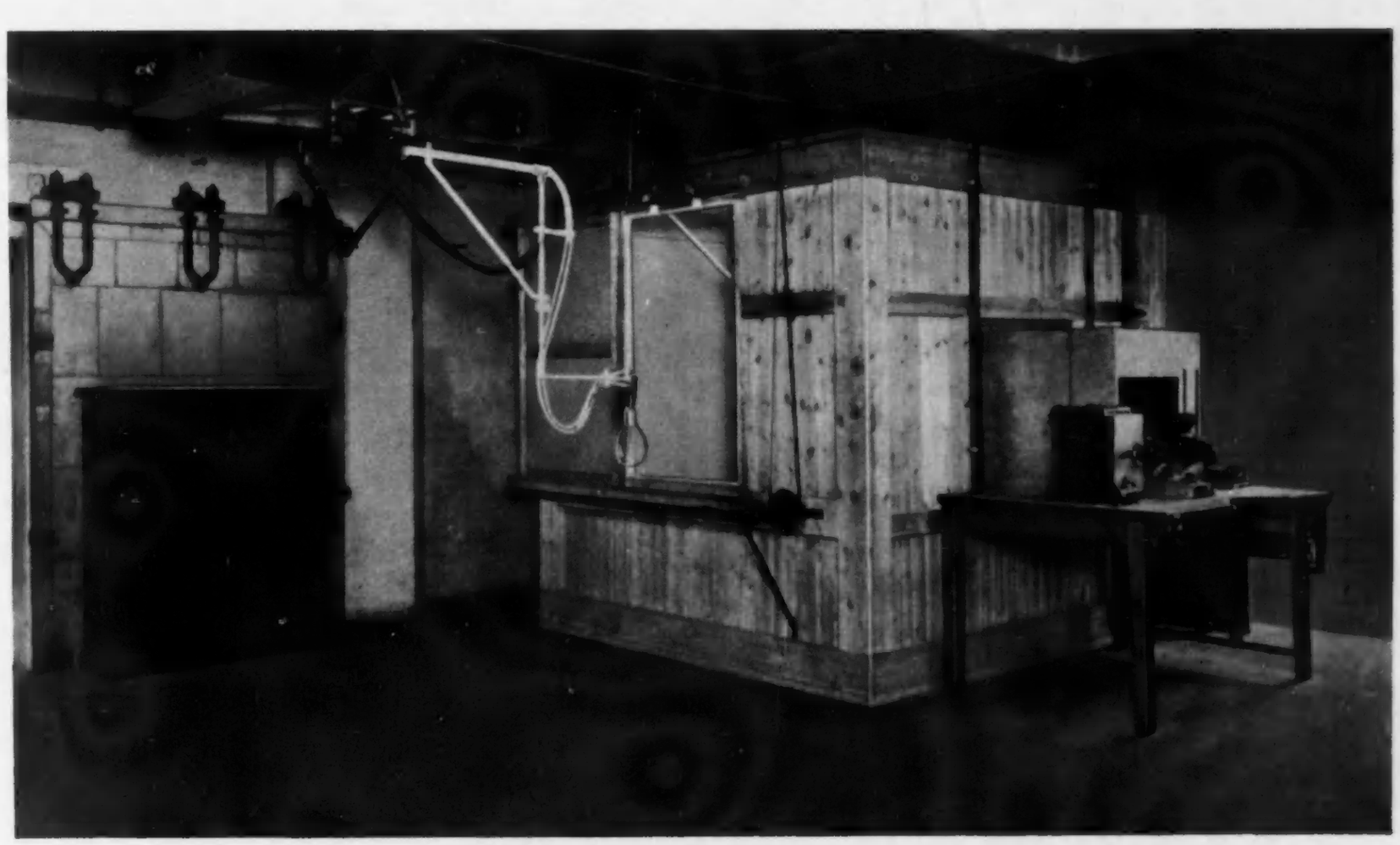

Fig. 7.—Photoelectric photometer for measuring lumens of 10 kW lighthouse lamps, etc.

Fig. 7 shows an equipment consisting of an 8 ft. side cubical photometric integrator equipped with a photoelectric light measuring unit. In principle this is similar to the photometer shown in fig. 2, the only essential difference being the size of the photometric integrator and its auxiliary apparatus.

This photometer has been installed in the Osram-G.E.C. Lamp Works particularly for the measurement of lamps of 5 and 10 kW sizes, but is equipped to measure even larger lamps should they be constructed. It is, however, equally suitable for measuring lamps of ratings as low as 500 watts. Because of the necessity for an easily controlled supply of current for the 10 kW lamps etc., and the need for very fine adjustment and constancy while the photometric measurement is made, consideration was given to the following schemes.

(a) Secondary batteries with resistances for fine adjustment of voltage.

(b) Motor-alternator set with induction regulator.

(c) Motor-alternator set with transformers and resistances.

(d) Motor-generator set with external voltage regulation.

(e) Motor-generator set with two generators.

Considering the relative merits of these five methods, all of which would probably give the necessary degree of voltage control, (a), (b), and (c) would be very expensive, while (b) and (c) would have involved the use of A.C. measuring instruments which was undesirable in this case. The available range of voltage adjustment, using method (d), would be insufficient to meet the case in question, and consequently method (e) was finally adopted.

It is believed that this is the first occasion on which this method has been adopted of providing a regulated voltage supply for photometry. In the past it has been the practice invariably to use secondary batteries and even to avoid charging them while they are in use for photometric work. The installation of this plant was therefore to some extent an experiment, and it has been very gratifying to find that, the mains voltage fluctuations being completely suppressed by the use of a synchronous motor, and frequency variations in modern conditions apparently being negligible, any voltage variations on the output side of the motor-generator set are quite inappreciable on the types of instruments used for making commercial measurements, though they might possibly be detected by potentiometer equipment. In any case, the operator is not conscious of them in using the equipment, although the photoelectric cells are undoubtedly more sensitive than the unaided eye would be.

The generator set shown in fig. 8 consists of three units, a synchronous motor coupled to two D.C. generators. The motor is of the revolving armature open type, is self-starting and operates on a 2-phase 4-wire, 220 volt, 50 cycle system at 1500 r.p.m. The two generators are of the shunt wound, interpole, open type machines, each with outputs of 25 kW at 125 volts, 1500 r.p.m., so that the total output of the set is 50 kW, thus providing adequate capacity to meet the needs of future developments in high wattage type lamps.

One of the generators is self-excited whilst the other is separately excited from the self-excited machine. Control of the self-excited machine is effected by a potentiometer rheostat with fine adjustment so that very close regulation of the voltage can be obtained.

The field of the self-excited machine is also controlled by a field regulator of such a resistance that it is not possible to reduce the voltage of the generator to a dangerously low value. However,

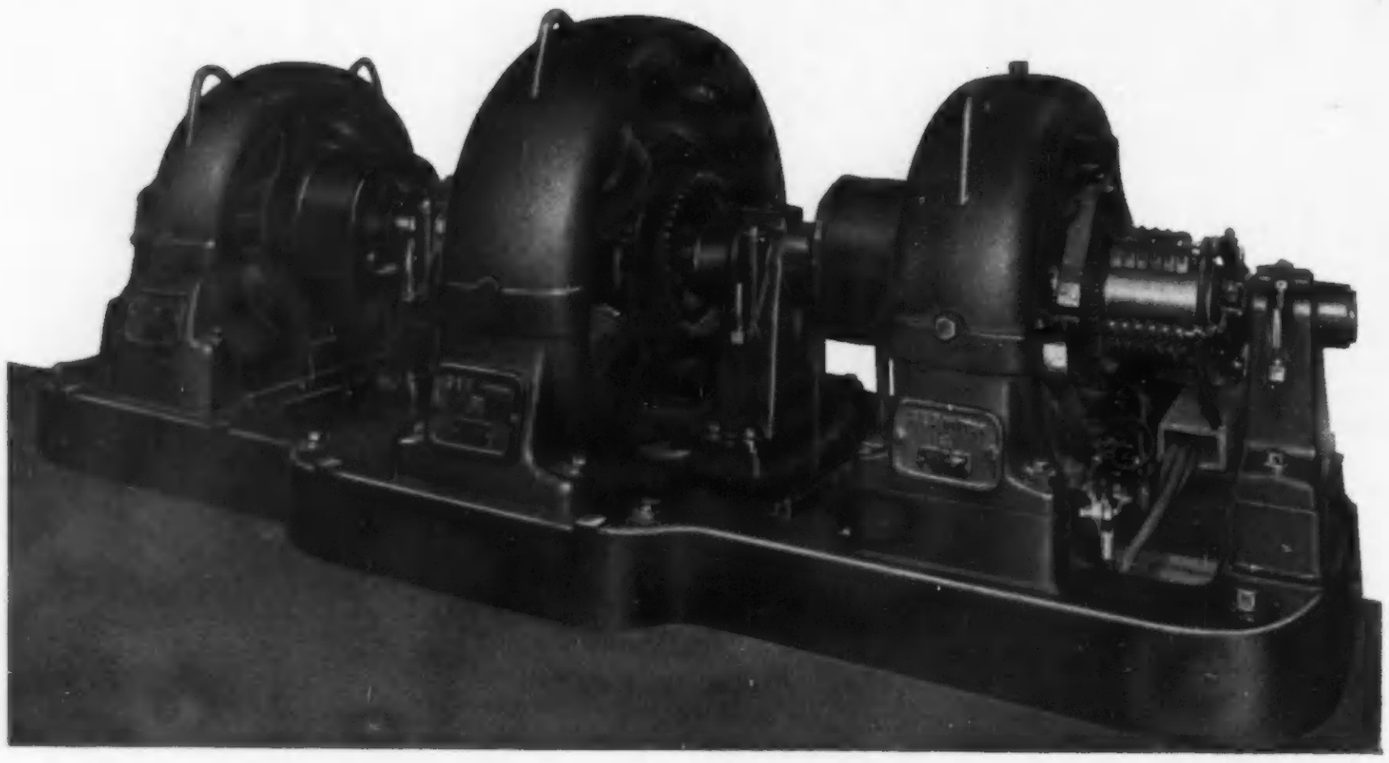

Fig. 8.—Motor-generator set supplying current for lighthouse and other large lamps.

this machine which also supplies the excitation for the synchronous motor field is normally operated at a constant voltage, (125 volts).

The control panel is shown in fig. 9. By means of the double pole, double throw switches, shown on the bottom right-hand panel, the two D.C. generators can be operated in series, in opposition, or in parallel, so that lamps of widely different voltage and current ratings can be operated with ease, and fine voltage control obtained under all conditions.

Referring to fig. 7 it will be seen that the field regulator rheostat is mounted on the left-hand side of the control table so that the lamp voltage is readily adjustable by the operator.

In order to facilitate the loading of the smaller lamp types (500 to 1500 W. sizes), two carriages mounted on overhead converging rails carry the lamp-holding gear. These carriages are connected

to a hauling gear operated by a handle so that when one lamp-holder is in the cube the other is outside, ready to receive the next lamp to be measured. A sliding door is used to close the aperture through which the lamps enter the cube. Both lampholders are wired to contactors on the main switchboard (fig. 9) which are operated by a tumbler switch on the control table and interlocked with the lamp

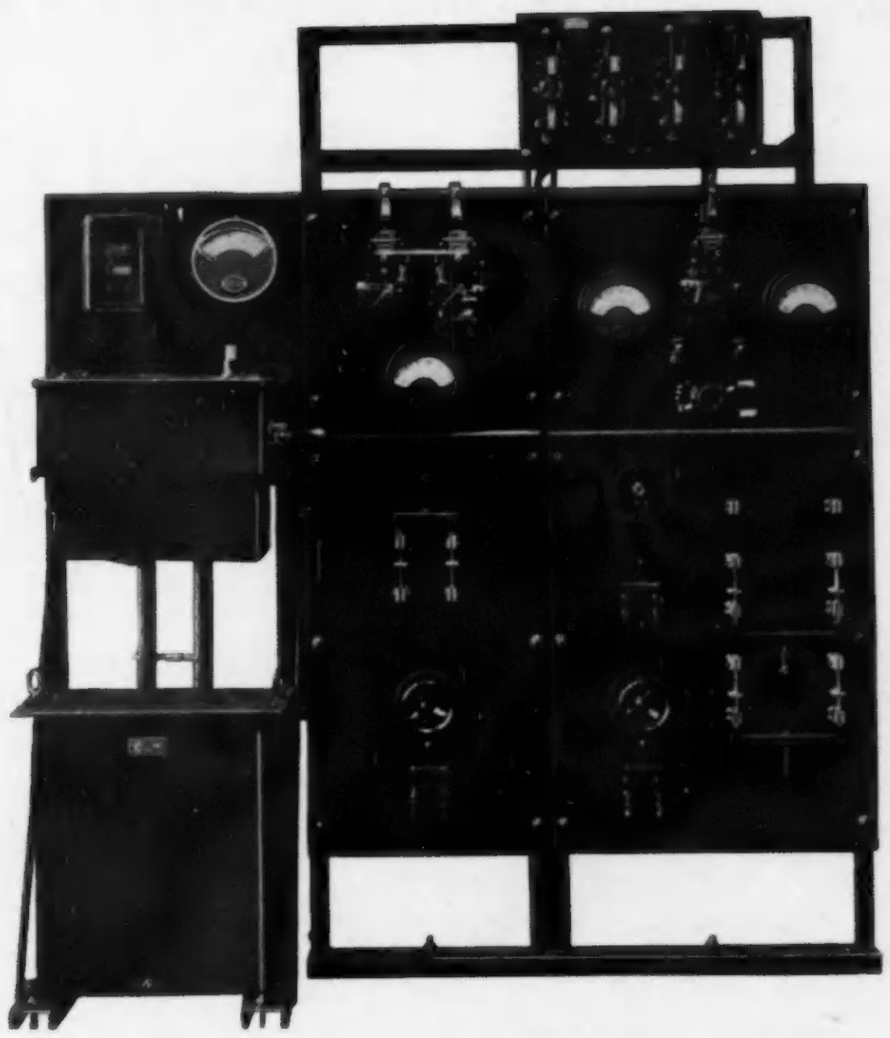

Fig. 9.—Control panels for motor-generator set shown in fig. 8.

carriages. Thus when the contactor is operated, the circuit of the lamp in the cube is closed, but the lamp-holder outside is "dead" and in this way the lamp can be changed without any danger of shock to the operator. By this arrangement, which only opens the circuit by the contactors, good contacts are assured in the lamp circuit with consequent freedom from voltage fluctuation at the lamp terminals.

The dual lamp changing mechanism is unsuitable for the very large lamps and special provision is made for the accommodation of 5 and 10 kW lighthouse lamps. In these cases heavy cables are led in through the floor of the cube to the lamps which are supported in the centre of the cube.

The complete photometer has been found to be extremely satisfactory in use and has made possible the precise measurement of very large lamps at commercial speeds under factory conditions.

PORTABLE PHOTOELECTRIC FOOT-CANDLE PHOTOMETER.

Finally, an attempt has been made to design a portable precision photoelectric illumination photometer[5] and the first experimental model (which was exhibited at the Physical Society Exhibition, London, in January of this year) is illustrated in fig. 10.

The design of this instrument has only been made possible by the development of the electrometer triode type of valve and a special type of K.M.V.6 photo-cell evolved for this purpose. Using the circuit in fig. 12, which is similar to that described earlier, it has been possible to make a compact and portable equipment.

The plungers P_1 to P_6 (fig. 11) are on the side of the photo-cell unit shown on the left in fig. 10, and operate short circuiting switches across sections of the grid leak and so change the sensivity and range of the instrument. In order to obtain sufficient sensitivity to the very low illumination values met with in street lighting work, grid leak values as high as 1000 megohms are used. Considerable difficulty has been experienced in making such high resistances sufficiently constant for this work and of suitably small size. An experimental grid leak of the evaporated metal film type is at present being tried; this is quite small and appears to be satisfactorily stable for this class of work. In order to maintain sufficiently constant the high insulation necessary in the grid circuit, the valves, photoelectric cell, grid leaks and switching gear are all embedded in paraffin wax in a metal box separate from the main control cabinet but connected to it by a five wire flexible cable which can be of any reasonable length. The batteries and controlling gear are contained in a wooden cabinet which has a compartment for housing the photo-cell unit when not in use. Illumination measurements are made by adjusting a potentiometer until a galvanometer spot is balanced

Fig. 10.—Portable photoelectric illumination photometer.

and then multiplying the reading obtained by the calibration factor for the particular scale range used. Whilst this photometer can only be considered to be in an experimental form at the moment, a new model is being designed which will be considerably smaller and lighter than the one shown in fig. 10, and will measure values as low as 0.002 foot-candle.

5. In course of publication.

ACCURACY OF COMMERCIAL PHOTOMETRY.

In the introduction to this article reference was made to the relative accuracy to which photometric measurements can be made by visual methods under laboratory and commercial conditions.

Since the introduction of photoelectric methods of measurements, a statistical study[6] has been made of the magnitude of the errors involved in making measurements under different conditions. It is not possible here to make more than a brief reference to this extensive study but it has shown that a marked

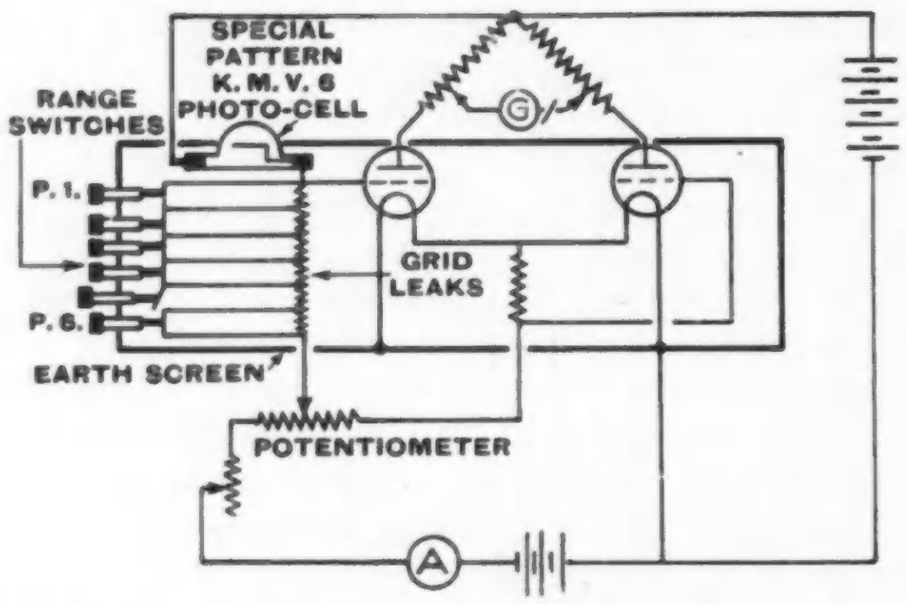

Fig. 11.—Circuit diagram of experimental portable photoelectric illumination photometer.

improvement in accuracy was obtained coincident with the introduction of photoelectric photometers (January 1929) which was steadily maintained to the end of 1931.

Since these results were published[6] greater attention to detail has enabled photoelectric photometers of improved design to be constructed and results for the first six months of the current year show a still further improvement in the accuracy of measurement.

6. B. P. Dudding, G. T. Winch, I.C.I., September 1931. Accuracy of Commercial Photometry.

In order to illustrate the improved accuracy obtained in the use of the photoelectric photometers for commercial measurements Table I has been prepared. In this the percentage number of observations made during the course of commercial photometry, differing by more than ±0.5 per cent, ±1.5 per cent and ±3.0 per cent respectively from measurements made on the same lamps in a laboratory under conditions of highest precision, are given both for visual and photoelectric measurements.

In considering these data it is necessary to note that the precision measurements which form the basis of reference are liable to small fluctuations, represented by the figure 20 per cent, given in the table under errors > ±0.5 per cent.

Table I.

Year.	Type of Photometer.	Proportion of Measurements differing from lab. measurements* by more than		
		±0.5%	±1.5%	±3.0%
1927	Commercial Visual ..	65%	30%	7%
1928	Commercial Visual ..	65%	30%	6%
1929	Commercial Photoelectric	45%	7%	0%
1930	Commercial Photoelectric	50%	9%	0%
Jan. to June 1932	Improved design Commercial Photoelectric	45%	0%	0%
1927-1930	Repetition Accuracy of Precision Visual Photometer. (Mean of two observers each making six photometric measurements—no colour difference).	20%	0%	0%

*—Average results for two observers each making six photometric measurements.

It is clear that the use of the photoelectric photometer for commercial work has practically eliminated differences greater than ±1.5 per cent (which occur quite frequently when carrying out the same class of work by visual methods) and that the proportion of differences greater than ±0.5 per cent is comparable with the repetition accuracy of measurements made visually by two observers under the best conditions in a laboratory.

The Handling of Ore for Export.

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Materials Handling Dept., Fraser & Chalmers Engineering Works of the G.E.C.

NOT the least among the many problems to be considered when mining ore for export are those connected with the most efficient and economical means by which the raw or treated material is to be transported to the shipping port and the method of storing and loading into ships.

In most cases the mines are situated at some considerable distance inland and are connected to the nearest port by a railway, or at least a ropeway. At the mines terminal of the railway the handling of the ore involves the loading of railway wagons from a storage pile or bunker, and necessitates the use of one or more conveyors and a system of loading into chutes. This system is intimately bound up with the layout of the general plant of the mine, and is arranged to suit the topographical conditions of the particular site.

At the shipping port terminal of the railway the arrangement and extent of the handling, storage and loading out plant depend entirely upon the nature of the coast line and whether or not existing port facilities are available.

Deep water for ships to lie alongside for loading is the first essential, if the ships are not to lie anchored out in a bay and be loaded from native craft or barges as has been the invariable custom in the past. In the case of virgin terrain, early opportunity should be sought for ascertaining by survey a suitable point where foundations for a jetty can be built and a ship loading jetty constructed. Where a shipping port already exists, however, it is occasionally possible to take advantage of existing facilities at the port by the erection of suitable plant, connecting the port with the mine property by a special railway, or by an extension of an existing railway.

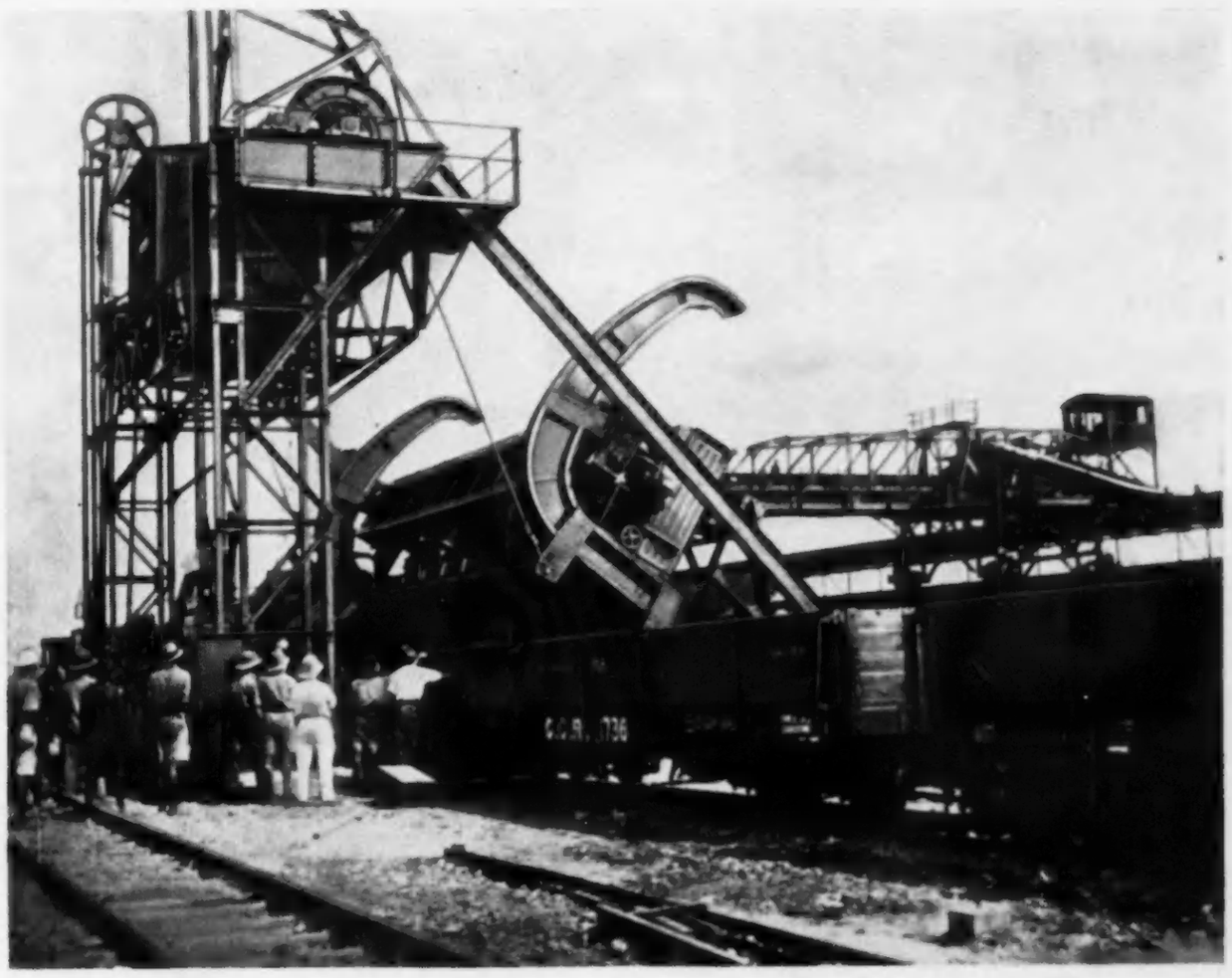


Fig. 1.—Wagon tippler at the harbour of Takoradi, West Africa, capable of tipping 25-ton trucks.

In some cases where such a port has flourished to the extent that the volume and nature of its export business has outrun the capacity of its existing facilities, local prospecting may show that a deep

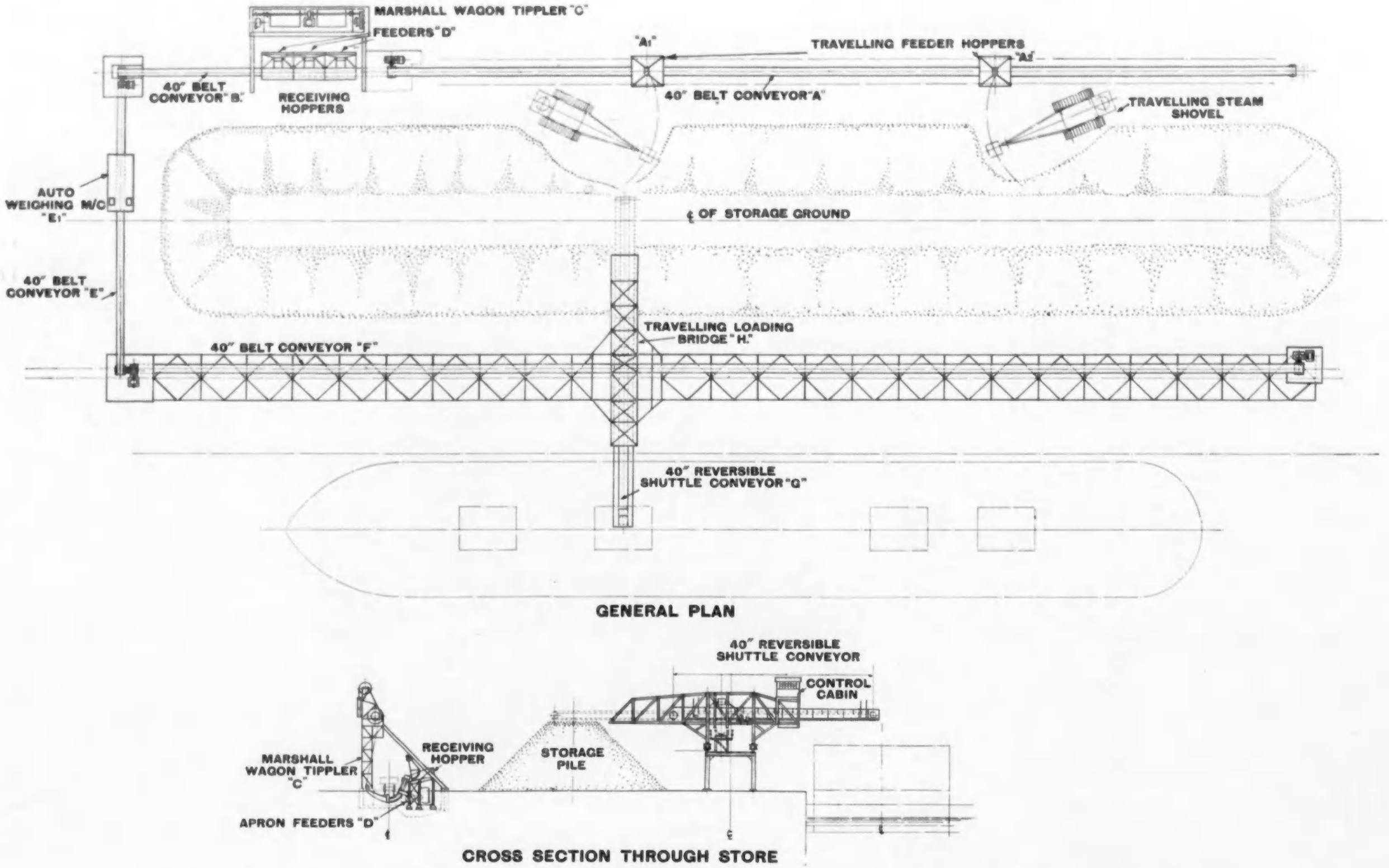


Fig. 2.—General arrangement of ore handling equipment installed at Takoradi harbour ; capacity 1,000 tons per hour.

water harbour could, with advantage, be constructed within easy reach of the settlement. In such a case, the need for a new harbour having already been created, powers are obtained for putting in hand the constructional work after due and careful survey has established the most suitable location, extent and type of the harbour, after which the old port either adjusts itself to the new conditions or is gradually merged into the new location.

New and up-to-date cargo handling plant is one of the inevitable corollaries of such a change in existing port facilities, and it is the purpose of the present article to describe both the installation of a complete modern ore handling and shipping plant and an extension of ore loading plant to existing equipment.

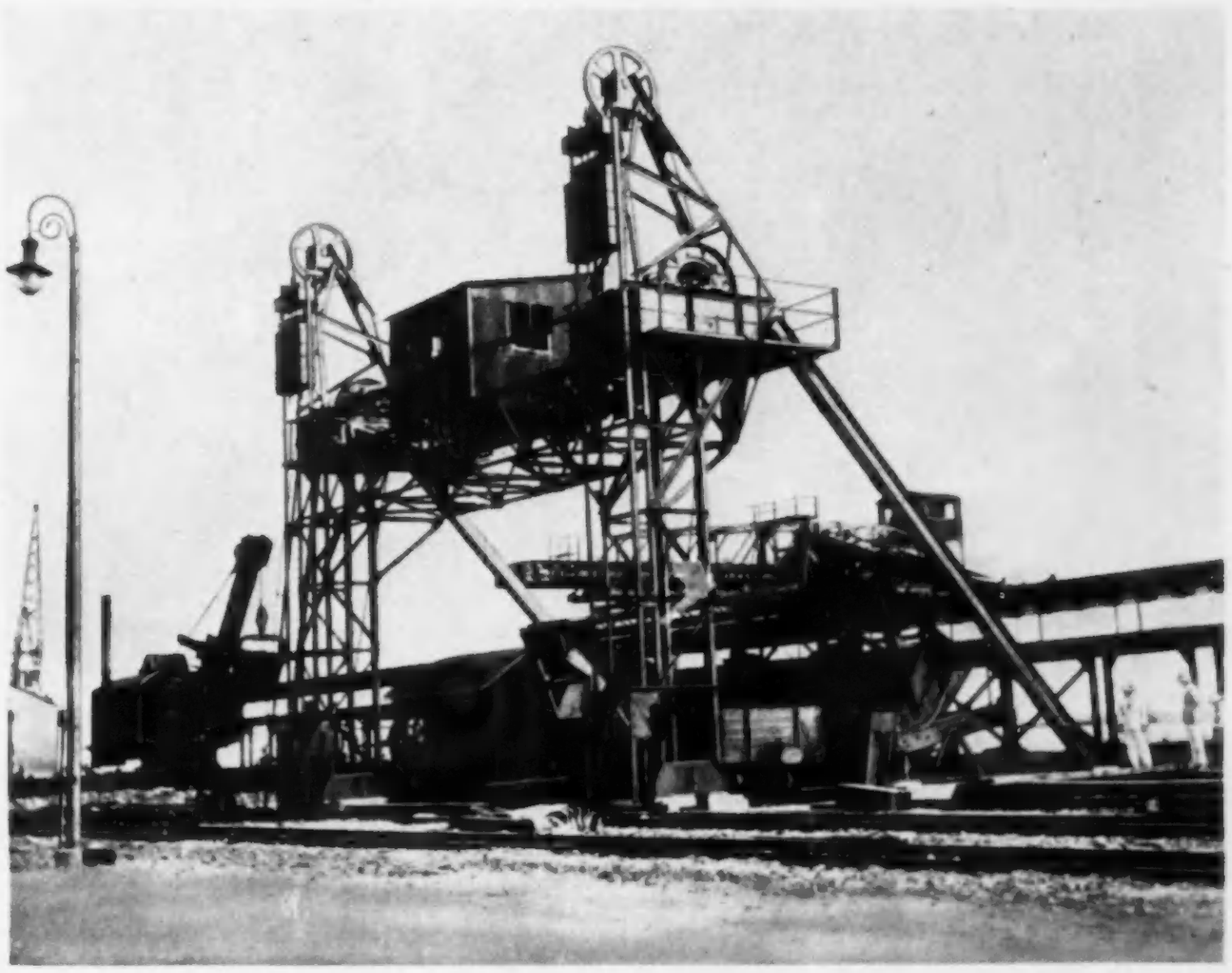


Fig. 3.—Receiving hopper situated beside wagon tippler.

THE TAKORADI SCHEME.

The completion in 1928 of the new harbour of Takoradi on the Gold Coast, West Africa, nine miles from Sekondi was followed by an exodus of shipping interests from the latter port to Takoradi, where the modern deepwater wharves and safe anchorage for the largest of passenger liners and cargo vessels inside its breakwaters, relegated Sekondi, with its old methods of barge and surf boat loading for cargo and embarkation of passengers, to a position of quite secondary local importance, if not actual eclipse.

Among the many products of the Gold Coast Colony are gold, cocoa, mahogany, palm kernels and manganese ore, large deposits of which latter were prospected and opened up in the neighbourhood of Sekondi about 1915. An immediate demand for this valuable mineral was created by the exigencies of the Great War, and Sekondi, being the nearest outlet for the export of manganese ore at this period, the shipment of ore rose from 4,000 tons in 1916 to 403,000 tons in 1927.

It will be appreciated that the rise of Takoradi with its immediate potentialities for the construction of modern cargo handling plant could have but one result, and in 1928 plans were completed for the installation of a ship loading plant for manganese ore along one of the deepwater wharves of the new port.

The erection of a modern ore loading plant capable of dealing with a capacity of 1,000 tons per hour was started in 1929 and in February of 1930 the plant was completed, and shipment of ore direct from rail into ship or into storage and reclaiming from storage began in the same month.

The immediate result of the opening up of this ore loading plant at Takoradi was the displacement of approximately 800 natives who were nominally employed at Sekondi under the old conditions of barge loading, and the employment of a small staff of about a dozen natives with one white overseer to operate and maintain the new plant.

When it is realised that one ship of 8,000 tons can be loaded by this new plant within the twelve daylight hours of one working day with the small staff mentioned, as against 10 to 14 days at Sekondi, employing 800 natives, it will readily be conceded that the economic advantages resulting from the installation of this modern ore loading plant are overwhelming and have amply justified the prevision of those responsible for its inception.

The design of the ore loading plant at Takoradi was entrusted to the Fraser & Chalmers Engineering Works of The General Electric Co., Ltd., by the African Manganese Co., Ltd., who are the sole exporters of manganese ore on the Gold Coast. After careful study of the local conditions and requirements, a final design was accepted for a plant capable of handling ore at the rate of 1,000 tons per hour direct from rail by means of a wagon tippler and into ship or storage via a scheme of belt conveyors, based on the Robins system, and a travelling loading bridge.

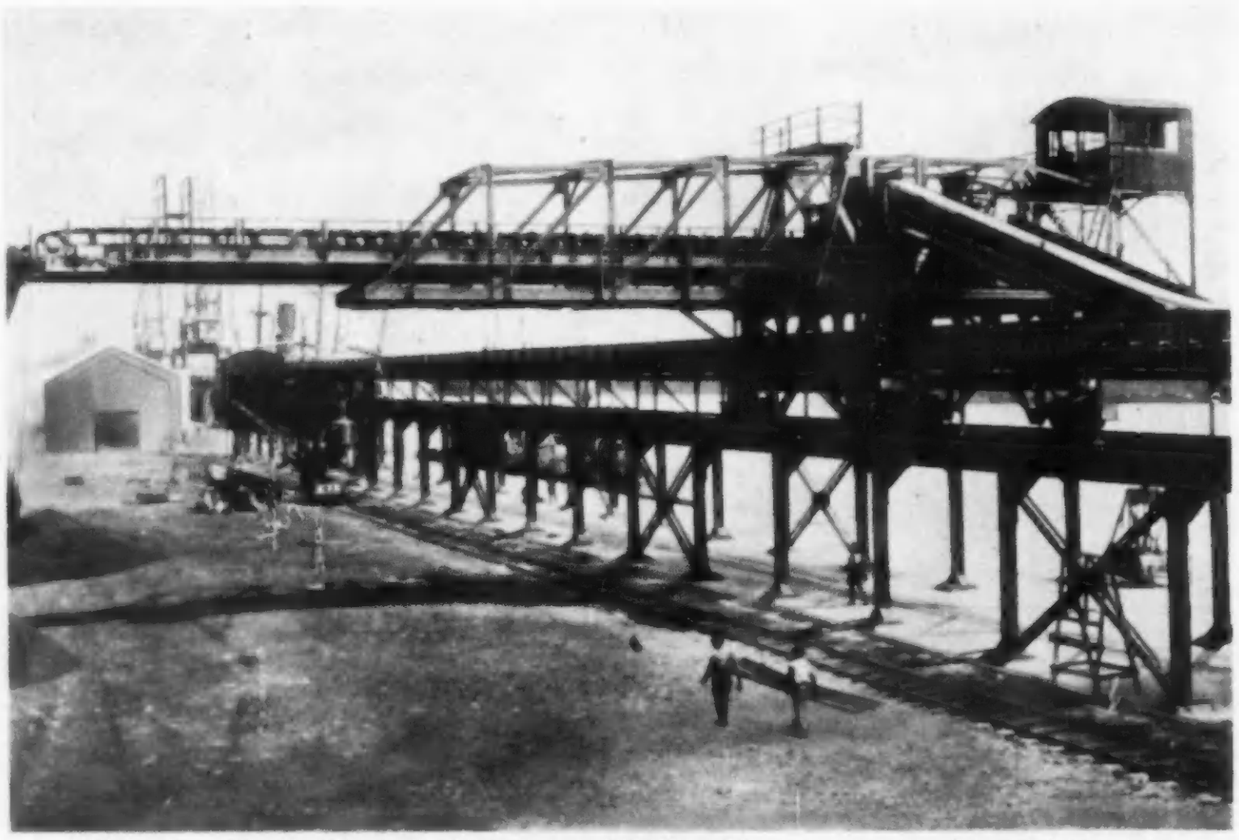


Fig. 4.—Travelling bridge provided with conveyor for delivering ore either into ship's hold or on to storage ground.

Reference to fig. 2 will show that the plant is arranged round three sides of a central storage ground capable of holding 31,000 tons of ore in bulk, and is divided into two parallel sections connected by an inclined cross conveyor at one end, the whole plant consisting of five 40in. belt conveyors, a wagon tippler, an automatic weighing machine, a travelling loading bridge and two travelling reclaiming hoppers.

Simplicity of operation was one of the objects aimed at so that the plant could be operated by semi-skilled native labour with the minimum of skilled supervision, and subsequent operation of the plant has shown that this object has been achieved.

For convenience of reference, the various sections of the plant have been indexed in fig. 2 as follows :—

A. Storage reclaiming conveyor.

A1, A2. Travelling reclaiming hoppers mounted over storage reclaiming conveyor "A."

B. Intake conveyor receiving from conveyor "A" or from receiving hopper of wagon tippler "C."

C. "Marshall" patent wagon tippler.

D. Steel apron feeders extracting ore from wagon tippler receiving hopper and delivering on to conveyor "B."

E. Inclined cross conveyor to outloading section of plant.

E1. Continuous "Westminster" automatic weigher mounted on conveyor "E".

F. Trunk conveyor on travelling loading bridge gantry.

G. Reversible shuttle conveyor in travelling loading bridge delivering ore direct into ship or on to storage ground.

H. Travelling loading bridge carrying reversible shuttle conveyor "G."

The method of operating the plant is as follows :

Manganese ore is brought down from the mines in trains of 25 ton capacity steel wagons which are shunted on to a track running through the wagon tippler "C," fig. 1. The wagons are then uncoupled and each is, in turn, adjusted in place on the hoisting platforms of the tippler which carries the wagon up and over, discharging the contents into a large receiving hopper, fig. 1.

From the receiving hopper the ore is drawn continuously by means of the three steel apron feeders "D" and delivered on to belt conveyor "B" which in turn delivers the ore on to conveyor "E" where it is automatically and continuously weighed through the "Westminster" automatic belt weigher "E_1"

From conveyor "E" the ore is delivered on to conveyor "F" which in its turn delivers the ore on to the reversible shuttle conveyor "G" in the travelling bridge "H," see fig. 4.

The shuttle conveyor "G" delivers the ore either direct into the ship's hold, fig. 5, or on to the storage ground, fig. 4, the frame carrying the conveyor being mounted on rollers and capable of being extended out either over the ship or over the storage ground.

The travelling bridge is mounted on a longitudinal gantry running the whole length of the storage ground so that it may be travelled to any hold of the ship whatever position the latter may take up along the wharf, or it may distribute ore over the whole length of the storage ground. The width of this distribution is adjusted by the travel of the shuttle conveyor inside the bridge. It will thus be seen that the whole system makes for great flexibility in operation.

Ore is reclaimed from the storage ground by means of two travelling "Ruston" steam shovels mounted on caterpillar tractors, each having a maximum bucket capacity of 4 tons. These shovels scoop the ore from the storage pile and deliver it into the two travelling reclaiming hoppers A1, A2, which in turn feed the ore on to belt conveyor "A." From conveyor "A" the ore is delivered on to conveyor "B" and so into ship by the same route as previously outlined from the tippler hopper feeders "D."

The advantages of the reclaiming portion of the plant are threefold, in that (1) it may augment the quantity of ore being tipped from the wagons; (2) it may load into ships when no train is available; and (3) it may be used if necessary to re-distribute ore from one section of the storage ground to another.

The whole of the plant is electrically operated and the conveyors are arranged for sequence starting and control, whereby each conveyor can only be started up in the proper sequence. Thus, the reversible shuttle conveyor "G" is first started up, and is followed in order by conveyors "F," "E," "B" and "A." It is not possible to start up any motor out of this order, thus ensuring that no ore can be transported over any one conveyor unless the following conveyor to which it feeds is also running. The control gear is so designed that failure of any one conveyor automatically shuts down the conveyor feeding it, but not the conveyors fed from it.

Emergency push buttons are located at suitable points so that if necessary all the conveyors can instantly be stopped by the pressing of any one of the buttons, after which the plant can only be started up again in the proper sequence.

The brakes on the wheel bogies of the travelling loading bridge are of the electro-mechanical type and are fitted with solenoids electrically connected to the controller of the travelling motor so that when the motor is running, the solenoid plungers are lifted, keeping the brakes free. A second or two after the current is shut off from the motor the plunger drops under the influence of a balance weight, which raises the brake shoes against the rail.

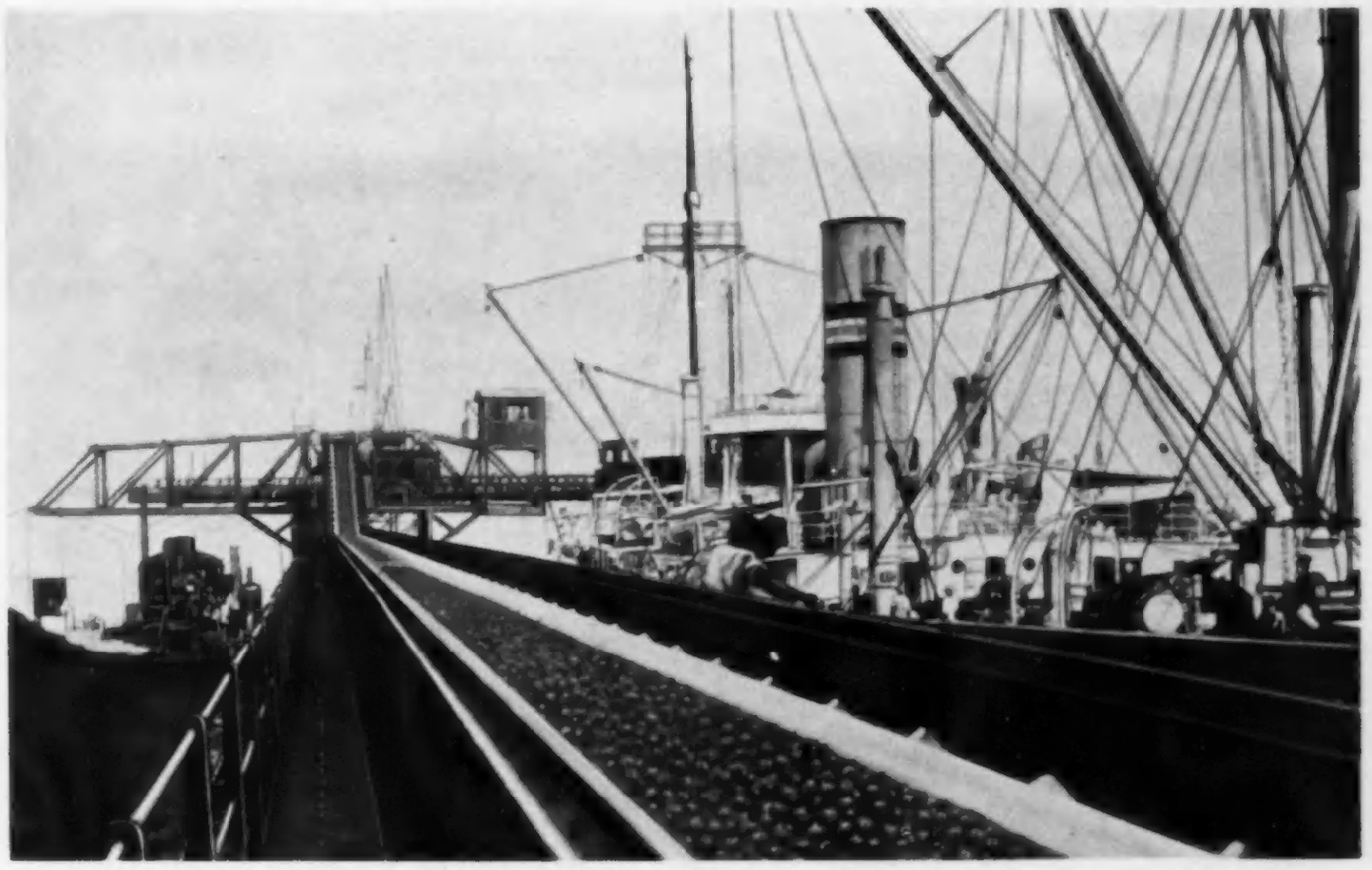


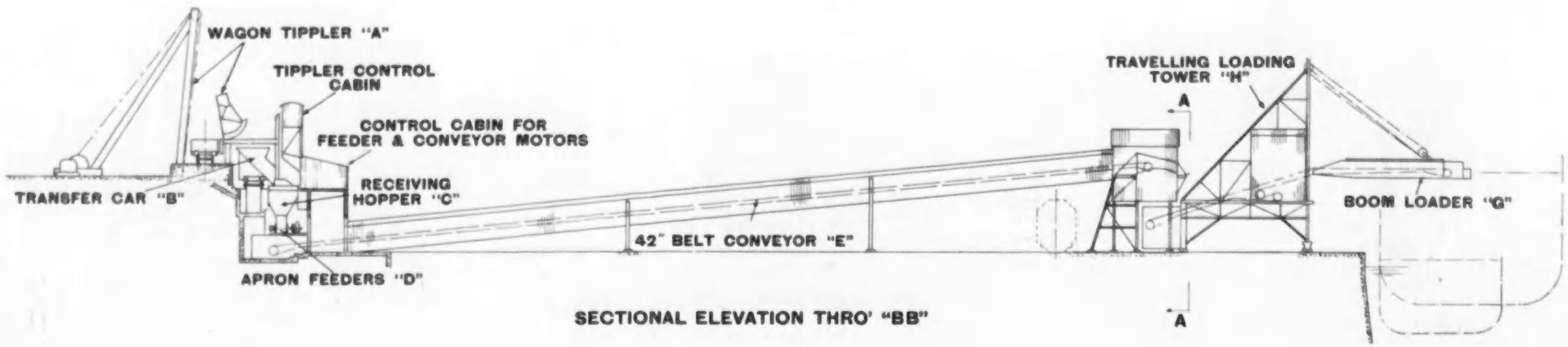
Fig. 5.—Another view of travelling bridge loading ore into ship's hold.

THE OXELÖSUND SCHEME.

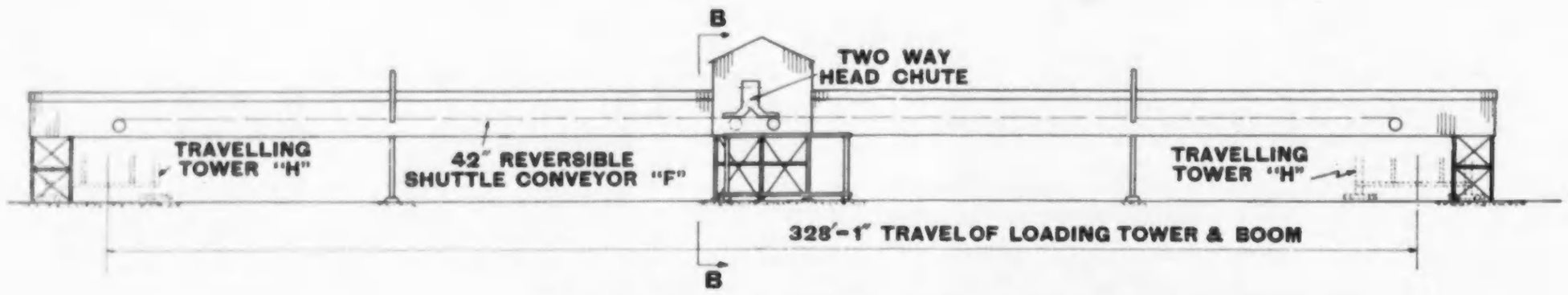
Following close on the successful inauguration of this ore loading plant at Takoradi came a scheme of a similar nature in Sweden for the export of Swedish ore, where a scheme of belt conveyors (Robins system) with wagon tippler, and travelling ship loading tower is installed at the port of Oxelösund, forming an extension to an existing plant for the loading of ore into ships or into storage.

The arrangement of this plant is in the form of a "T" with the wagon tippler at the base, and the travelling loading tower running along the top, as shown in the diagram, fig. 6.

The new extension is designed to deal with 750 tons of ore per hour and is arranged immediately adjacent to the existing storage ground which is situated alongside the main railway from the mines, fig. 7. A subsidiary line is laid along one side of the



SECTIONAL ELEVATION THRO' "BB"



SECTION THRO' "AA" SHOWING SHUTTLE CONVEYOR & GANTRY

Fig. 6.—General arrangement of ore handling plant at Oxelösund ; capacity 750 tons per hour.

storage ground and parallel to the main line, and carries an electrically-operated steel transfer car of 90 tons capacity. This car is arranged for side dumping, the ore being dumped into the storage ground or reclaimed from storage.

One of the problems which had to be faced in designing this plant was the fact that at certain times of the year the ore in the wagons arriving from the mines is frozen in one mass, and suitable means had to be provided for breaking it up before delivering it into the transfer car and on to the conveyors.

lifted bodily and turned over, discharging its contents over the breaking plate and grid into the transfer car "B." The breaking plate, being provided with vee-shaped projections, breaks up any large masses of frozen ore and any lumps which are too large to pass through the fixed grid are split up by hand.

The transfer car "B," which is capable of holding two wagon loads of ore, can also be used when reclaiming ore from the storage pile, being filled by a grab from the overhead storage bridge and run into position over the receiving hopper "C." From the transfer car the ore is discharged direct into the

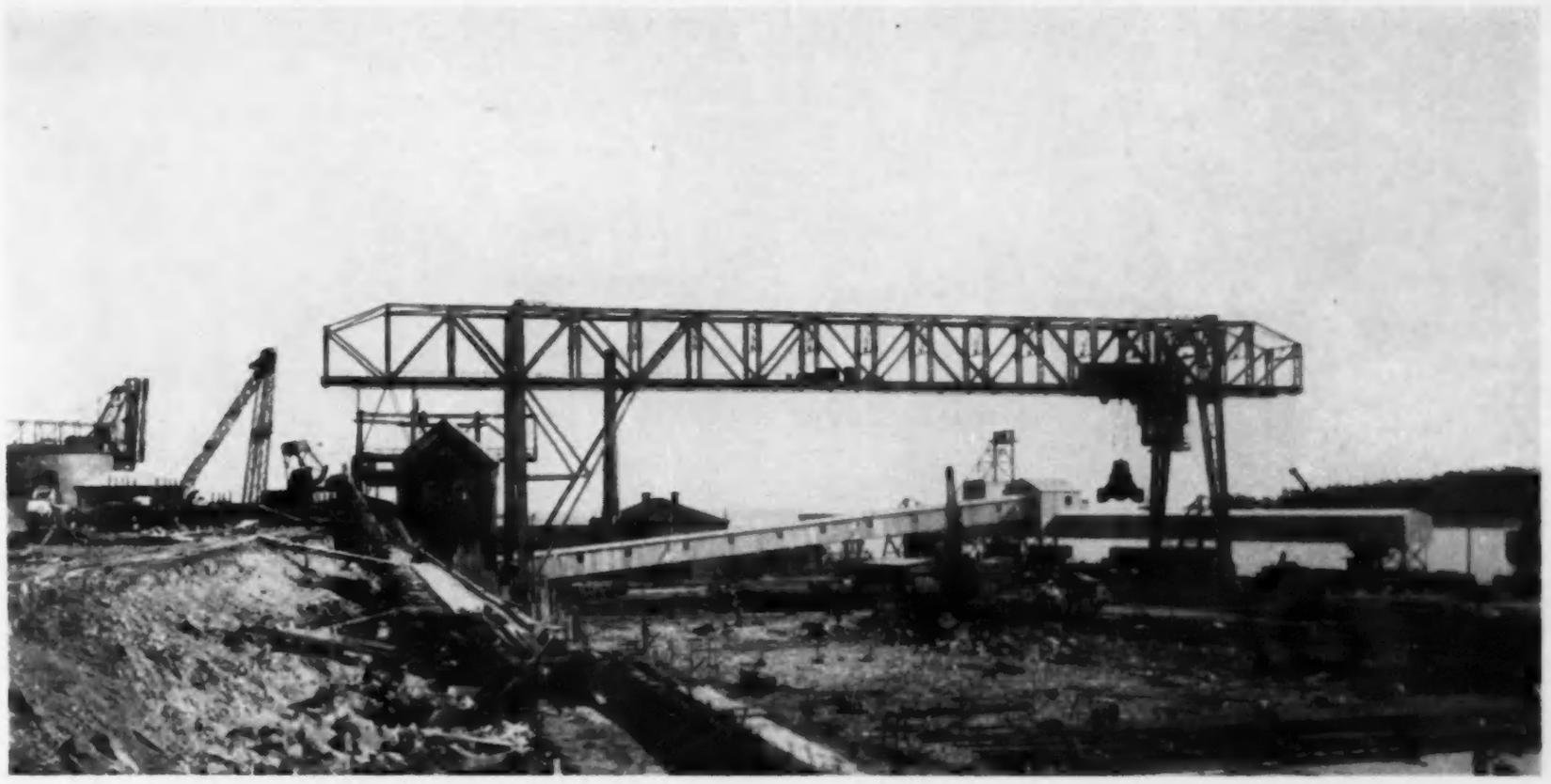


Fig. 7.—Site of new extension to ore handling plant at Oxelösund, Sweden.

On this account it became necessary to include, as an integral part of the wagon tippler, fig. 8, a special anvil for breaking up the frozen ore into easily handled lumps, together with a fixed grid to retain any lumps larger than the conveyor could handle.

For convenience of reference the various sections of this plant have been indexed in the diagram, fig. 6, as follows :—

A. Wagon tippler and breaker bench.
B. Existing electrically-operated transfer car.
C. Receiving hopper.
D. Steel apron feeders.
E. Trunk conveyor to shiploading section.
F. Reversible shuttle conveyor.
G. Boom loading conveyor.
H. Travelling loading tower.

The sequence of operation of the plant may briefly be described as follows :—

Trains of steel wagons, each carrying 45 tons of ore, are received from the mines and are shunted on to the track running through the tippler "A." Each wagon is uncoupled and adjusted in position on the tippler hoisting platform. The truck is then

receiving hopper "C," whence it is continuously drawn by means of the two steel apron feeders "D" and delivered through a chute on to the tail end of the trunk line conveyor "E" which conveys it up to the cross shuttle conveyor "F." The shuttle conveyor "F," being reversible in direction of running and capable of travelling from one end of the enclosed gallery to the other, can be attached to either end of the travelling loading tower "H" so that the ore may be discharged on to the boom conveyor "G" and delivered direct into the ship's hold. At the end of the boom conveyor is fixed an adjustable trimming plate for distributing the ore evenly over the hold.

The whole of the plant is electrically operated and an interesting feature of the control system is the method by which the two apron feeders "D," the trunk line conveyor "E," the shuttle conveyor "F" and the boom conveyor "G" are simultaneously controlled from one point, where the five control equipments are mounted on one frame with their corresponding shunt field regulators mechanically coupled to give simultaneous speed control of the whole of the conveyors.

Each panel is fitted with a double pole change-over switch, the upper contacts allowing individual selection and operation of any particular motor for testing purposes, and the lower contacts providing sequence control of the whole of the conveyor motors, a double pole single throw control switch being provided for starting purposes.

Fig. 8.—Wagon tippler taking 45-ton trucks.

Failure of any one conveyor equipment also shuts down the conveyors feeding into it, but not the conveyors fed from it. On elimination of the fault, the stationary conveyors can be restarted, without stopping the conveyors which have continued to run, by operating the shunt field regulators in order to close the full field interlock. Trolley wires and collectors are provided for the travelling sections of the plant, namely, the reversible shuttle conveyor "F" and the travelling loading tower "H."

The control of the tower traverse equipment is effected by a master controller having a central "off" position, four positions "forward" and four positions "reverse," a no-volt position being provided without notch, between the "off" position forward or reverse. The acceleration of the motor is under the control of the current lock-out devices which are attached to the contactors and are independent of the speed of operation of the master controller.

A magnetic brake on the motor is automatically applied when the master controller is brought to the "off" position but the clamp brakes on the wheels of the tower bogey are applied under the control of a special delay relay mounted on the panel which prevents the application of the bogey brakes until approximately twelve seconds after current to the motor has been cut off, thus giving the tower time to slow down and ensuring a smooth stop. The travelling loading tower is provided with special electro-mechanical brake bogies, similar to those fitted to the travelling bridge on the ore loading plant at Takoradi.

The wagon tippler hoist and the loading tower boom hoist are similarly controlled, limit switches being fitted to prevent over-running, while emergency push button switches are arranged at suitable points whereby the whole plant may simultaneously be brought to a standstill should any emergency arise.

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